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Implementation of recycled thermoplastics in furniture design: development of a seat stool

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Implementation of Recycled Thermoplastics in Furniture Design

Development of a Seat Stool

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ABSTRACT

The problem with plastic products, is that they create a big negative environmental impact while having a reduced amount of useful life. This means, that waste plastic is accumulating at alarming amounts and rates. Thermoplastic demand will continue throughout the years, therefore, the best solution, for now, is recycling. Furniture, can be ideal examples to implement recycled thermoplastics. Their prolonged use creates a valuable contrast to the short-term life of common plastic objects. If we want to promote and communicate the importance of making recycled plastic products, we need to design an object that fulfills today's needs and transmits the importance of recycling.

The outcome of this project is the creation of a tripod stool named "Gibada". It is a viable product solution for our current plastic waste problem. This furniture contains a recycled HDPE (High-Density Polyethylene) seat and three solid beechwood legs. The stool's seat achieved an attractive and unique color pattern that evokes curiosity on the material's origin, thus, it promotes and raises awareness of the benefits of implementing recycled thermoplastics in furniture design.

Keywords: design, HDPE, furniture, recycled, thermoplastic

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Dedicated to my Mom and Dad, who have always supported in all my decisions. Thanks for being the perfect example and showing me that education and perseverance are key elements in life.

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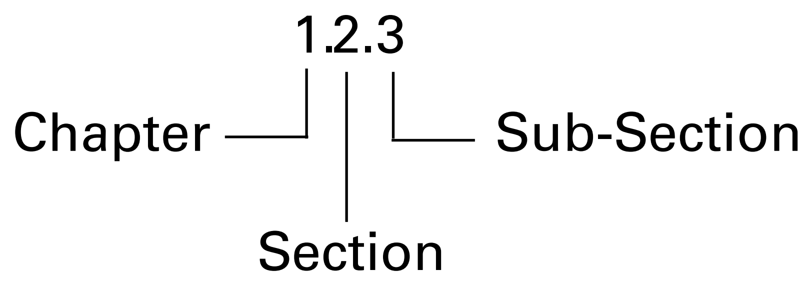
PREFACE

This research paper is the final evaluation for the master's program "Industrial and Product Design" imparted by the University of Porto in Porto, Portugal. This project was developed during a one-year period, September 2017-2018.

We want to thank all the companies that helped in any manner with the completion of this project.

APA style is used as the reference method for all the sources quoted and paraphrased.

When referring to chapter, section and sub-section location, the following format will be applied.



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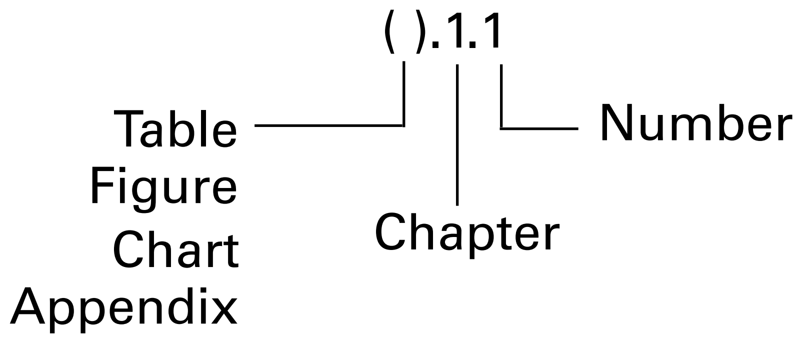

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ABBREVIATIONS

LCA - Life Cycle Analysis

PS - Polystyrene

HDPE - High Density Polyethylene

ABS - Acrylonitrile Butadiene Styrene

PET - Polyethylene Terephthalate

MDF - Medium Density Fibreboard

CAD - Computer Aided Design

CNC - Computer Numeric Control

MDMS - Meaning Driven Materials Selection

RTA - Ready To Assemble

HCI - Hydrogen Chloride

NHC -Nylon Hydrogen Cyanide

LDPE - Low Density Polyethylene

PE-HD - Polyethylene High Density

PE-LD - Polyethylene Low Density

PVC - Polyvinyl Chloride

PP - Polypropylene

UV - Ultra Violet

MDD - Material Driven DEsign

DIY - Do It Yourself

DFE - Design for the Enviornment

WRAP - Worldwide Responsible Accredited Production

ASTM - American Society for Testing and Material

INTRODUCTION

Plastic is a very common material utilized in modern furniture. Its use started in the 1950s and still today is widely used. Plastic implementation have a broad amount of advantages; however, the negative impact it is causing to our environment, is overpassing its good qualities.

Currently, plastic is the best material for packaging and transportation purposes. It is light, inexpensive, easily malleable, strong, resistant to environmental changes, and very durable. All these positive qualities have allowed plastic to replace to other traditional and less environmental harmful options such as; wood, paper, cardboard and glass. Almost 40% of the European plastic demand was dedicated to packaging, and this specific material utilization, is expected to grow worldwide up to 12% yearly (PlasticsEurope, 2016; Shah, Hasan, Hameed, & Ahmed, 2008).

The big problem with plastic packaging is the negative environmental impact it creates as compared to the reduced amount of time it is being used. The packaging only serves as a transportation vehicle or protection device, once the object inside is accessed, the container is immediately discarded. Most of this plastic does not even fulfill a long-term use, thus, becoming big waste problem. (Luijsterburg & Goossens, 2014). Currently, this is our biggest environmental issue with plastics, waste amounts are increasing, while materials alternatives, and re-utilization rates are not keeping up.

Plastics are divided into different categories, thermoplastics being the type of polymers that is industrially preferred. They are commonly used for packaging and containment applications. The environmental advantage of thermoplastics is their ability to be re-used. However, low prices in virgin materials, lack of technological advances, and degradation after consumer use, have maintained the industry sector uninterested in implementing recycled plastic into their products.

Plastic demand will continue, therefore, the best solution for now, is recycling. We need to increase the number of products that can use recycled thermoplastics. Current market tendencies are demanding eco-friendly objects, there is no better time than now, to promote and produce goods that implement recycled materials.

The recycled plastic's quality may widely vary depending on the zone, weather, consumer use and disposal method. Certain industry sectors like; automotive, pharmacy, food, and health, have strict standards and policies of the materials being used. Thus, they have a clear preference in using raw components over recycled ones.

The furniture industry does not contain any type of strict policies that bound them to specific quality levels in their raw materials. Even though quality in wood and recycled plastics can widely wary, this has not stopped the furniture industry production.

Given the furniture's nature, its dimensions, and materials used, they are normally seen as an objects that will last for years, if not decades (Leslie & Reimer, 2003). Furniture can be the ideal product to combined with recycled plastics. Their prolonged life creates a positive contrast to the short-term life of common plastic products.

If we want to promote and communicate the importance of making recycled plastic products, we need to design an object that connects in diverse forms with the user. It needs to make a physical and emotional bond with the future enjoyer. Furniture can be considered to have these types of virtues.

1.1 BACKGROUND AND PERSONAL MOTIVATION

Solutions and ideas commonly rise out of specific needs or the urgency of resolving issues we find in our daily lives. Two years ago, I started my master's degree in Porto, Portugal. Last year, we were asked to develop a workshop for the mentally ill as our final project, inspired by the project "Precious Plastic" , our class decided to implement recycled plastic as our main focus.

Through experimentation and diverse testing methods, several processes and objects were made from recycled plastic. In our case, we created a fast and easy method to fabricate stools made from plastic and wood waste. The final products were beyond our expectations, the results were so satisfying, that we decided to use this material as the focus for our master's degree thesis.

1.2 OBJECTIVES

The main objective of this project is to design and create a functional furniture that is made partially or fully from recycled plastic. If developed correctly, the product itself should also generate awareness of today's worrying plastic pollution situation.

A second intention is to design and create an eco-efficient product. Our focus is to use recycled plastic; thus, we need to enforce eco-design techniques to effectively fulfill our goals.

The third objective is to design taking into consideration, the current global needs. Increase in population, and global preference of moving into big cities, is restricting and reducing the current living spaces. We intend to attack this problem with the implementation of efficient multi-functional furniture.

1.3 LIMITATIONS

The lack of a companies' sponsorship and the low budget for this project created several limitations. These factors were analyzed in the initial stages, in order to find real and possible alternatives.

Presented below, are the current project's limitations:

-The product's design and concept will be limited by the manufacturing possibilities of the University of Porto's workshops and laboratories.

-A real prototype (dimensions and material) will be made to obtain palpable results.

-The design will be made on a global basis; no country, culture or tradition shall influence the outcome of the product.

-All plastic utilized during the project must be recycled.

-The component's dimensions and volume will be limited by the available manufacturing processes and equipment.

-All plastic utilized should be provided by local recycling companies. This will reduce time from collecting, sorting, cleaning, and shredding.

1.4 CHAPTER STRUCTURE

Chapter two includes all the theoretical investigation that was used during all the different phases. It justifies and helps validate this project. The third chapter, explains all the different methodologies and processes that were implemented to develop this thesis. Chapter four, presents how we implemented all the information from the previous chapters into our project's needs. Then, in chapter five, we display the results obtained. In chapter six, we discuss our results within the desired goals and context of this thesis. Chapter seven, contains the conclusion of this project and the final chapter displays all the references used.

INTRODUCTION

THEORY

This project intends to create the best possible version of a sustainable furniture using recycled plastic; although full sustainability will not be the focus, it will have a big impact on the final design.

2. 1 SUSTAINABLE DESIGN

Raw materials are being depleted due to our high consumption demand and increasing population. These actions are specially affecting manufacturing goods that utilize non-renewables resources. It is the responsibility of the designer to have these factors in mind when creating new products, the materials and manufacturing methods, should have sustainable design applied to them (Ljungberg, 2007).

Sustainable is an extensive and complex word having several different meanings appearing throughout the years. Sustainable products, manufacturing methods and industrial processes used today should not affect negatively on the resources that will be used for future generations. There are three components (Figure 2.1) that compromise sustainability: economic, social and environmental (Charter & Tischner, 2017; Greene, 2014; Ljungberg, 2007; Yüksel & Kiliç, 2015).

Sustainable design does not have a definite methodology and it is constantly changing over the years due to market's influence and environmental degradation. Everybody has a different point of view of what can be considered as "sustainable". Although there is no evident meaning to the word, we have to do our best in finding and applying the best solutions and tools available in this important topic (Karlsson & Luttropp, 2006).

The area of sustainability that will be covered in this project will be the use of recycled plastics. This will be applied on the important main components, although, not on the entire final product. The designer will try and make the best usage of the available tools and resources to make furniture that creates the least negative impact to our environment.

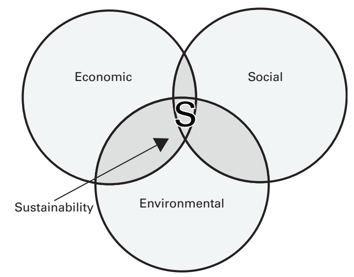


Figure 2.1 Three factors that compromise sustainable design.

(Greene, 2014).

2. 1. 1 *Eco-Design*

Design can be considered the most important part of a product's development process, most of the big decision are taken during this stage. It has been estimated that 85% of the issues with manufactured goods, were a result of a mediocre design practice. It is estimated that 5% of a product's total cost is dedicated to the design phase (Figure 2.2); however, around 75% of the production's costs are estimated or, committed in this early stage (Ullman, 2010). This means that design can be the easiest and cheapest way where big impacts can be applied.

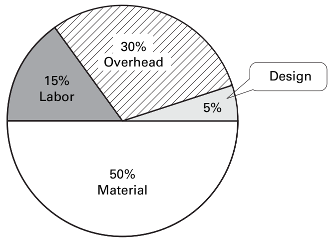


Figure 2.2 Distribution of manufacturing costs of a product

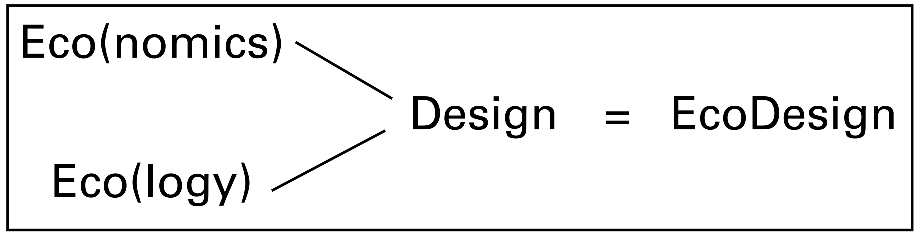
(Ullman, 2010).

When trying to create "eco-friendly" products, the design stage becomes the most important topic. Early design strategies that considered environmental issues can have an enormous positive impact on creating a sustainable product (Ramani et al., 2010).

Eco-Design has the same issue as the term sustainability design, analyzed as a word, it can have several meanings or interpretations. If we analyze the roots of the word itself, we can see that it is directly linked to the environment, "eco" meaning house in Greek corresponds to our living surroundings. "Eco" is also applied in economics and ecology (Figure 2.3); thus, we can suppose that eco-design is designing with relationship with our environment or, taking into consideration our natural surroundings (Karlsson & Luttropp, 2006).

Figure 2.3 Similarity between words that use the linguistic root of "eco".

(Karlsson & Luttropp, 2006)



Even if there are several perceptions of this specific word, they all revolve around the benefit of caring for our habitat. Below, we can see Table 2.2 that gathers several "eco-design" meanings with their respective authors.

Table 2.1 Different meanings of "eco-design" from different authors.

Meaning	Reference
"provide a benefit to the customer/user at the lowest environmental/ economic cost"	(Luttropp & Lagerstedt, 2006)
"the integration of environmental aspects into product design and development"	(2002 International Organization of Standardization, 2002).
"minimizing the product's environmental impact across its entire life cycle, starting already from its design stage"	(W Wimmer, Ostad-Ahmad-Ghorabi, Pamminger, & Huber, 2008)
"EcoDesign aims to combine business-oriented design goals and environmental considerations"	(Karlsson & Luttropp, 2006)
"Ecodesign is the systematic integration of environmental considerations into the design process of products (both goods and services)"	(Rocha et al., 2011)
"Eco-design, which is also known as Design for the Environment (DFE)." "DFE can be seen as a broad and general concept for promoting a sustainable design"	(Ljungberg, 2007)
"Its main objective in the improvement of product development methods is to reduce environmental loads"	(Karlsson & Luttropp, 2006)
Sustainable solutions are products, services, hybrids or system changes that minimize negative and maximize positive sustainability impacts e economic, environmental, social and ethical e throughout and beyond the life-cycle of existing products or solutions, while fulfilling acceptable societal demands/needs"	(Charter & Tischner, 2017)
"Eco design is decreasing the environmental effects during the life cycle, material design and better material design."	(Yüksel & Kiliç, 2015)
"Ecodesign or Design for Environment, DFE, covers any design activity which aims at improving the environmental performance of a product"	(Hauschild, Jeswiet, & Alting, 2004)

Implementing eco-design into a product's design can be achieved in numerous ways. Certain rules or checkpoints can be applied into the object's features, a clear example of this methodology is Luttropp's 10 Golden rules (Luttropp & Lagerstedt, 2006). He summarizes several articles on eco-design practices and comes up with ten simple rules to follow to make an efficient sustainable product.

Besides following specific rules or checklists, there are a variety of tools and techniques that can help us improve the sustainability of a product. Bovea's paper investigates and analysis the available tools in the market that help us apply eco-design techniques (M. Bovea & Pérez-Belis, 2012). He mentions that these tools widely vary in their content and method of application. Since they are not interrelated, they have not developed a standardized or generic approach, that could be applied to most cases.

The lack of standardization and the broad different methods of applying eco-design has become a problem in the industry sector. There is a clear trend in the production of "green" goods but there is still a big confusion of what can be considered a sustainable product (Dangelico & Pujari, 2010). These factors cause a negative impact; thus, companies, struggle and fear when trying to change their strategies or manufacturing methods to help the environment.

Even if there is no clear technique on how to apply efficient eco-design into a companies' product, it is a fact that the green market will increase in the future (Dangelico & Pujari, 2010). These sustainable upgrades come with a price that few companies are willing to pay for (Luttropp & Lagerstedt, 2006), even though there is evidence, that applying eco-design methods offer a clear short-term economic benefit (Plouffe, Lanoie, Berneman, & Vernier, 2011).

2. 1. 2 *Life Cycle Analysis*

If we are trying to create a sustainable product we must analyze the whole life cycle of the product itself, from its manufacturing process all the way to its disposal. Life Cycle Analysis (LCA) is one of the many available tools that can help us address and improve a product's environmental impact (2006 International Organization of Standardization, 2006). This is one of the most worldwide recognized and accepted tools (M. a. D. Bovea & Vidal, 2004).

In the design stage, LCA can be applied in a qualitative manner in order to analyze different application scenarios, and discover at an early stage, possible improvement areas (Hauschild et al., 2004). In this section, specific characteristics of the furniture industry will be briefly analyzed under the LCA methodology.

Through a designer's point of view, the easiest way of reducing the environmental impact of a product is throughout the proper selection of materials. Today, the furniture industry utilizes a wide variety of components in their finished goods (González-García et al., 2011), whose decisions can have a direct impact on our environment's health. A study in Finland analyzed eight different furniture manufacturing processes and concluded that 38-90% of the green house emission are related to the choice of materials employed (Linkosalmi et al., 2016). We can conclude that in the furniture business, the election of materials is crucial when applying eco-design.

Wood is an excellent material applied in furniture industry and has been used for thousands of years (Smardzewski, 2016). Being a natural material, wood by obvious reasons is biodegradable, however, this does not mean it is not harmful to our environment, there are several factors during its manufacturing stage that can affect our habitat. Using a study carried out on Spain as an example, nine different wood-base furniture companies where evaluated with a LCA analysis to study how different eco-design strategies would help reduce the CO_2 emission and their carbon footprint. When prioritizing the use of recycled materials in their furniture, they noticed that almost half of the products analyzed, showed an important positive improvement in their environmental impact (González-García et al., 2011).

The life cycle analysis can be a very complicated topic to analyze, since there are several factors to be considered and sometimes, the result can be difficult to understand, making the design stage more complicated (Luttropp & Lagerstedt, 2006). In this project, we did not apply this methodology to our design; however, it is still an important topic to discuss when considering eco-design techniques applications.

2. 1. 3 *Designing with Recycled Plastics*

Recycling can be one of the best ways to reduce the environmental impact of a manufactured good. In the case of plastics, using recycled instead of virgin material, is currently the best way to reduce the negative damage the polymer industry is causing to our ecosystem (Hopewell, Dvorak, & Kosior, 2009).

Plastics are subdivided into two categories, thermosets and thermoplastics. In this project, we will focus on the use of thermoplastics since, they are the easiest types of polymer to recycle and reshape (Shen & Worrell, 2014).

Improving and making better design practices are a key factor in creating a more sustainable manufactured good (Shen & Worrell, 2014). The use of recycled plastic, will be one of the strongest "green" characteristics of this furniture. To close the product's life cycle, when the object is no longer useful, it easily should be able to be recycled. A clear strategy would be to design a recyclable product that utilizes recycled materials instead of virgin materials (Maris, Froelich, Aoussat, & Naffrechoux, 2014).

Recycled plastic is not a common raw material used in the industry sector, but, technology, social trends, market direction, and plastic production are creating new investment opportunities with this "waste" material. Not only is it becoming a new direction in the business sector, also, the use of recycled thermoplastics, are maximizing the environmental benefits compared to using the traditional virgin plastics (WRAP, 2010).

There are several considerations we need to discuss when designing a product that utilizes recycled plastics. One of the most important factors is the need to mark or indicate the type of thermoplastic we are utilizing. In this manner, consumers and companies will be able to recycle the product's parts or components. The American Society for Testing Materials (ASTM) organization created a standardized coding system (ASTM, 2013) to mark and register the different thermoplastics resins (Table 2.1) used in the industry. This is a key aspect we need to include in our product.

Marking or coding recycled polymers is of great importance, many plastic components are being produced with no coding standard, thus complicating the future of recycling process. As an actual example, social trends, cost reductions, and easy access have made 3-D printing readily available to many. This manufacturing method is a clear case of how easily objects are being processed with no type of coding or category system being applied (Hunt, Zhang, Anzalone, & Pearce, 2015).

Presented below are some characteristics that must be applied in order to improve an object that utilizes recycled polymers. (Information based on several articles (Hunt et al., 2015; Ljungberg, 2007; Maris et al., 2014; Shen & Worrell, 2014; Thierry, Salomon, Van Nunen, & Van Wassenhove, 1995).).

Table 2.2 Thermoplastic resin type coding along with typical applications.

(Shen & Worrell, 2014).

Number	Abbreviation and Name	Typical Applications
1 PETE	PET: polyethylene terephthalate	Bottles and flasks for soft drinks, mineral water, detergents and pharmaceutical products; blister packs; packaging for ready meals
2 HDPE	HDPE: high-density polyethylen	Thick-walled applications such as bottles and flasks, barrels, jerry cans, crates and jails; films for refuse bags; packaging for carpets and instruments
3 V	PVC: polyvinyl chloride	Blister and press-through packs for medication; films for perishables
3 V	PC: polycarbonate	Refillable milk bottles; specific refillable packaging for liquids
4 LDPE	LDPE: low-density polyethylene	Foil and film, such as shrink wraps, tubular film, sacks and covering wraps for bread, vegetables, fruit and carrier bags
4 LDPE	LLDPE: linear low-density polyethylene	Ultra-thin films: elastic wrap foil or stretch films
5 PP	PP: polypropylene	Buckets, crates, boxes, caps for bottles or flasks, transparent packaging for flowers, plants, confection products; yogurt and dairy product cups; industrial adhesive tapes
6 PS	PS: polystyrene	Food service disposables; boxes and dishes for meat products and vegetables; boxes for ice; boxes for video tapes
6 PS	EPS: expanded polystyrene	Buffer packaging for household devices, electronics and instruments; flasks and pipettes for the medical industry; egg packaging and fast food packaging
7 OTHER	Other	Other packaging

Characteristics to be applied are:

-The recycled materials should maintain its mechanical and chemical properties.

-Parts and components made from recycled plastic should include the correct thermoplastic recycling code.

-Parts must be able to be sorted by recycling companies.

-Must be easy to transform and sort having in mind a good cost-to-performance ratio.

-Avoid the use of composite materials.

-Use of fasteners instead of glue or screws.

-Components must be easy to disassemble and categorize.

-Additives, fillers and coatings must be avoided if they affect the recycling process.

2.1.4 Eco-Design in Furniture

An evaluation of several articles and standards (2002 International Organization of Standardization, 2002; Ljungberg, 2007; Luttropp & Lagerstedt, 2006; Rocha et al., 2011; SIEMENS, 2000; Wolfgang Wimmer & Züst, 2003) was made into the project's specific needs. Several characteristics were implemented to obtain the best representation of a sustainable furniture stool. Given the project's limitations and focus some actions were not considered in this stage (for example, packaging, sales, marketing, client information, transport or assembly instructions).

Eco-design aspects considered in this project are presented below:

-Reduce the number of components.

-Minimize the variety of materials.

-Minimize the usage of installation or assembly tools.

-Employing recycled materials.

-Usage of cleaner production techniques.

-Use of better quality materials that will prolong the product's life and reduce maintenance.

-Design for reuse, recovery and recycling.

-Not using toxic substances, materials, finishes, additives or coatings.

-Taking into account human health during manufacturing (proper safety gear and avoid usage of hazardous-health materials).

-Use local materials, the shorter the distance the transport travels, the better.

-Low energy consumption during manufacture.

-Design for easy end of life disposal or treatment.

-Design for prolonged usage.

-Minimize the number and variety of fasteners, connector or fixings.

-Design of removable connectors that are easily disassembled and not destroyed in the process.

-Reduce the number of steps to assemble/disassemble.

-Avoid using composites, mixes, blends, coatings, additives or alloys.

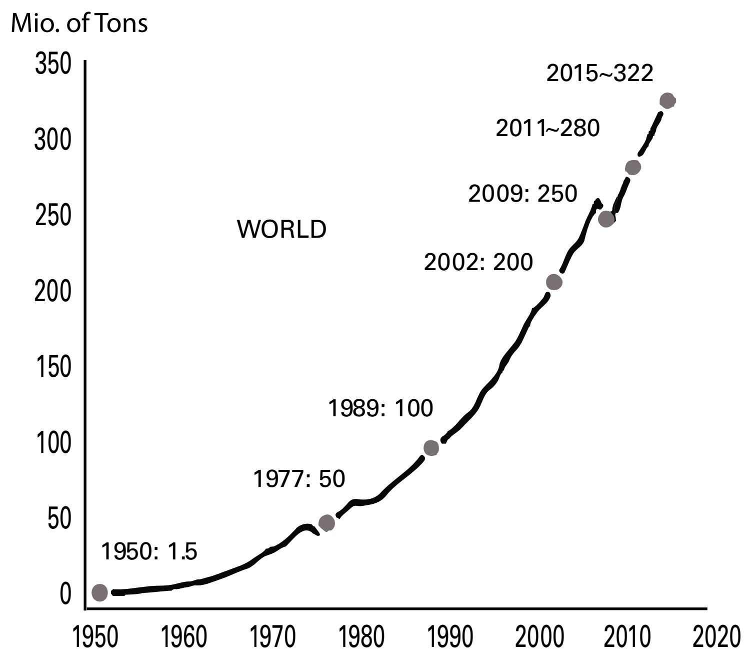
-Materials must be able to be recycled after prolonged use.

2.2 RECYCLED PLASTIC AS A MATERIAL

The main issue with plastic is the amount that is being produced and thrown away with no future use. Landfills are receiving more and more plastic due to the increasing demand, although this material is not the majority it has a bigger impact on the environment than the rest of the other trash (paper, metal, wood, etc.). According to Plastics Europe, plastic production has increased significantly since the 1950s (Chart 2.1), here has been an 8.6% annual growth rate since the 50s until 2015, this material has become so important to our society that it even surpassed in steel production by volume in 1989 (PlasticsEurope, 2015).

Chart 2.1 Plastic production worldwide in millions of tons.

(PlasticsEurope, 2015).



We need to find more and more products or solutions that utilize this great material, it has great characteristics mechanically and physically, it is easy to re-use and recycle and more important of all its abundant and production continues to grow. We need to take advantage of this waste material and make people understand these polymers can be re-used, therefore, the recollection and separations of this plastics can be easier.

It is hard to determine if recycled plastic would create a decent product. Degradation does occur, what is difficult to determine is if the plastic is still functional, too many factors (UV light, heating exposure, mechanically wear, etc.) involve in the degradation of post-consumer plastics (Vilaplana, 2007). However, the recycled material will always vary landfill to landfill, city to city and country to country.

The main objective of this paper is to analyze and discuss if recycled plastics can be used in the manufacturing of furniture. There will be no scientific emphasize of the material itself, but discussion will be made of the advantages and disadvantages of utilizing this post-consumer material. Design will also be considered as a key factor in applying this used material into products which in this case will center in furniture. The objective is clear when applying eco-design into furniture, the main focus is to use the fewer materials and energy in the manufacturing process and make sure this applied material is the most efficient in environmental impact, cost and social awareness (Yüksel & Kiliç, 2015).

2.2.1 Plastic Introduction

Before we go into details about plastic production and how it affects our world, we first need to understand this unique material. Plastics are a human-designed material that utilizes fossil fuels and other raw materials for their production, they are currently used in many objects in our modern life, currently 4% of the world's crude oil is use in the manufacturing of plastic resins. (Andrady, 2003). Different from what everybody thinks, plastics actually help us build a more sustainable world, their low energy and raw material consumption during their manufacturing phase makes this material very efficient, also, the fact that they can be easily reused after post-consumer use helps us reduce the creation of virgin polymers (PlasticsEurope, 2016).

Plastics are considered a new material due to its short usage when compared to other typical materials like wood, stone, metal, etc. In the industry, its low cost and high mechanical efficiency has increased is used throughout the years. Plastics started being commercially used in the world around 60 years ago, their low cost, flexibility, high versatility and the ability to transport or protect biological material have made it the common material in a variety of applications. This material has become so popular and common in all everyday products, it is even hard to imagine living without them (Andrady, 2015).

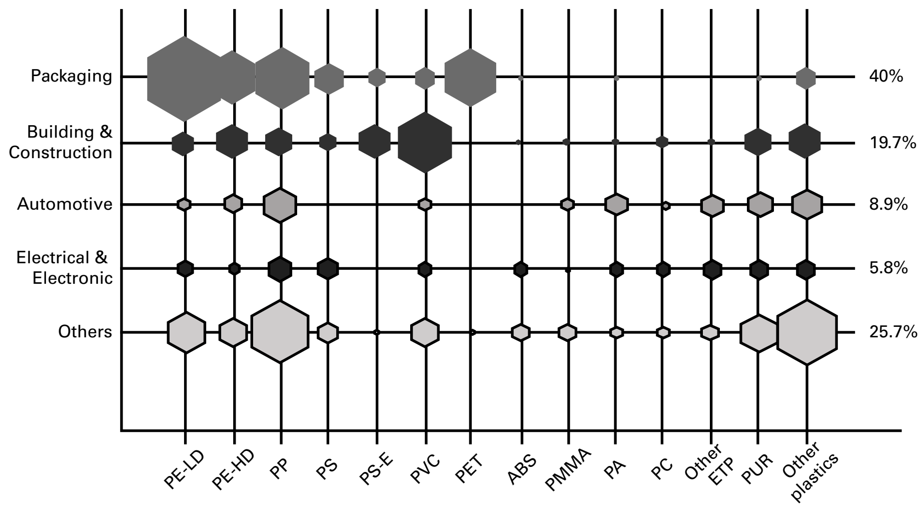
As mentioned before plastics are a material made from fossil fuels, the biggest problem about these polymers is their impact to the environment. Not only do they pollute when being manufactured but also their post-consumer life is not eco-friendly at all. One of the main advantages of plastics is the ability to resist bacterial or fungal penetration, this same characteristic makes it difficult for the natural biodegradation process to occur, these polymers are considered non-biodegradable materials since their biological deterioration process is too slow and may take several years, therefore, they can be considered to have a permanent or longer life span compared to other materials (Chanda & Roy, 2006; Shah et al., 2008).

2. 2. 2 *Plastic Waste*

One of the best applications plastics have are used in packaging solutions, ranging from medical applications all the way to the food industry, it has become part of our lifestyle, it is one of the top choices for several companies to transport safely their products. It is highly used to package food, pharmaceutical and medical products, detergents and household liquids, cosmetics and other endless applications. Almost 40% (Chart 2.1) of the European plastic demand was dedicated to packaging, this specific material utilization is expected to grow worldwide up to 12% yearly (PlasticsEurope, 2016; Shah et al., 2008).

Chart 2.2 Plastic demand in Europe, divided by polymer type in 2015

(PlasticsEurope, 2016).



Plastic packaging has changed the way we know and use daily products, it has replaced materials like glass and metal especially in the medical and food industry. The big problem with this specific application of plastic, is the short-life, the packaging only serves as a transportation vehicle or protection device, once the object inside is reached the packaging becomes discarded immediately, most of this plastics don't even fulfill a long-term use, this becomes a really big waste problem. (Luijsterburg & Goossens, 2014).

It is critical we search for new methods or applications to either reduce the ecological impact of plastic packaging or find better and more efficient ways to recycle this "one-time" use material. Packaging waste must be considered the worse type of trash due to its usage-time ratio is totally inefficient when compared to the damage it's causing to our environment.

2. 2. 3 *Recycling*

Recycling should be one of our biggest priorities today, tons of used plastic objects are thrown away into landfills and never get the opportunity to be re-used. According to Plastics Europe in 2014, Europe produced 59 million tons of raw plastic, in that same year they registered that 7 million tons were collected for recycling, meaning that only 12% of this material was recycled in that specific year (PlasticsEurope, 2016). Given the impact plastic waste is generating in our ecosystem, we need to promote and recycle the most amount of post-consumer plastic.

As mentioned before, plastics are divided into two categories, thermoplastics are the only type of polymer that can be directly reprocessed without adding any chemicals or additives (Chanda & Roy, 2006). Thermosets can be melted and shaped only once, although they can be reused, it is not a common material to be recycled in the industry, it is a complex procedure than needs the usage of diverse chemical processes (Shen & Worrell, 2014).

Packaging is the area with the biggest volume consumption of plastic, therefore, this is where recycled plastics should be involved the most, however, the safety concern of the material being transported or safeguarded may affect the use of this post-consumer plastics. There are strict regulations that revolve in the use of packaging systems, we have to consider that the object inside this package cannot be in contact with contaminants, therefore, is difficult to use recycled plastic in this applications (Vilaplana & Karlsson, 2008).

2. 2. 4 *Issues with Recycling*

There are three main challenges involved in the mechanical recycling of plastics: thermal-mechanical degradation, processing of complex polymer mixtures and degradation during lifetime. (Ragaert, Delva, & Van Geem, 2017). This are only physical characteristics that affect polymers after their disposal, there are several other factors that make recycling a difficult process.

Costs of recycling

Another key factor that affects the promotion of recycling is the cost behind the process. The plastic recycling process has a lot of stages, this can represent a high use of energy and resources to achieve a high-quality material. The low prices of the virgin plastic pellets make it difficult for companies to be motivating in using recycled polymers in their current products (Ragaert et al., 2017).

To this day, there are a lot of companies that do not trust the application of environmental tools or actions to their products or processes. This lack of confidence applies most of the times to medium and small industries that fear investing in something that wrongly, is considered to be not cost-effective. (Plouffe et al., 2011)

Mechanical separation

Polymers need certain conditions to achieve complete compatibility, there are certain characteristics like polarity, molecule weight and hydrogen bonding that must be matched. It is difficult to find plastics that meet the previous conditions, therefore, most polymers cannot be mixed or blended into a homogeneous solution (Chanda & Roy, 2006). Mentioning this, we need to separate all the different plastics types and then search for the characteristics so that they can be compatible, this would take a lot of time and money, making the production of recycled objects meaningless and not efficient. The use of energy to search and classify these different plastics would create a bigger impact than the benefit of the recycling itself.

Plastics do not corrode or decompose easily by natural means, they also adapt and interact effortlessly with additives or composites. These previous abilities mentioned are also one of the reasons why plastics are so hard to recycle, polymer products may be found in landfills with all sorts of composites, mixtures and additions that may even change the composition of the original material used (Shen & Worrell, 2014). There are several techniques to mechanically separate used plastic, the chosen process will depend on the type of post-consumer components being fed and the expected properties

in the outcome material or composite.

Design problems

The physical separation of the used plastics is not the only problematic area, the designing of products is also a key area when trying to simplify this waste recollection. When fabricating objects that use plastics, a lot of factors should be considered, a simple rule would be to use the same type of polymer, if using distinct types of plastics, compatibility should be considered. Designers should think beyond the disassembly of the devices, they should analyze and think about the future life and recyclability of the materials being used (Bogue, 2007).

We need to find a balance between the best way to design a product thinking about its future recyclability and focus, improve and promote the recovery of used plastics. Eco-design is an area than can help us solve this problem. “Ecodesigning recyclable materials means to make them transformable and sortable with an acceptable cost-to-performance ratio.” (Maris et al., 2014).

Plastic degradation

When working with recycled plastics we need to consider two mayor activities that degrade the properties of a polymer. The normal wear and tear made by the user and the mechanical damage applied when recycling (shredding, heating, cleaning, etc.) the polymer itself (Ragaert et al., 2017).

Several studies ((Joshi, Lehman, & Nosker, 2006; R. Santana & Manrich, 2002; R. M. C. Santana & Manrich, 2003; Vilaplana, 2007; Vilaplana, Ribes-Greus, & Karlsson, 2006)) analyzed differed post-consumer thermoplastic for their physical and mechanical properties, they all concluded that some type of degradation occurred even at a minimum level. Although certain characteristics varied from each other in the different cases analyzed, we can conclude that a plastic suffers physical and mechanical deterioration along its lifetime and during the recycling process itself.

There are some many variables that can affect the outcome of a reprocess plastic after consumer use. It is practically impossible to determine the exact properties in the outcome of a plastic in the recycling procedure. The only controlled area is the recycling process itself, although we do not know the actions that affected the material during its lifetime or the amount of times it has been reprocessed. The problem with recycling is that every time the plastic gets reprocessed, mechanical properties will be lowered with each repetition (R. Santana & Manrich, 2002).

2. 2. 5 *Advantages of Recycling*

Recycling should be treated as a priority in at least all types of thermoplastics, the plastic demand is increasing, therefore, we must consider that this re-using process should increase as well, all products must be designed thinking of recycling as the best option for the end-of-life activity.

<u>Efficiency</u>

Plastic waste can end-up with very different outcomes, they can be recycled, incinerated, disposed, buried or piled up in landfills. A report made by the association Worldwide Responsible Accredited Production (WRAP) analyzed different disposals (recycling, incineration with energy recovery, landfill and pyrolysis) of plastics and evaluated the most beneficial one to our environment. "The results show that mechanical recycling is the best alternative regarding the climate change potential, depletion of natural resources and energy demand." (WRAP, 2010). According to Chart 2.3, several cases where analyzed and recycling is the preferred eco-friendly alternative compared to the other common reprocessing techniques.

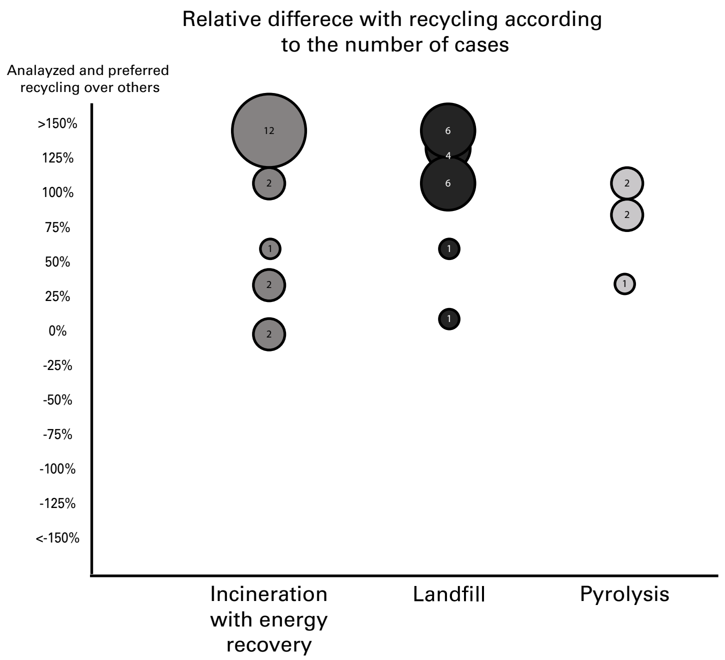


Chart 2.3 Difference between recycling and different end-of-life options. The bubble represents the number of cases analyzed with those processes.

(WRAP, 2010)

LCA studies (Arena, Mastellone, & Perugini, 2003; Perugini, Mastellone, & Arena, 2005) in the Italian plastic recycling system concluded that mechanical recycling was the best waste management option from an environmental perspective. This shows that recycling is the correct way of handling plastic waste, the next step would be to create products or valuable goods that use recycled thermoplastics as their main raw material.

<u>Economic Advantages</u>

Eco-design can cause an economic impact not only directly applied in savings, this area can help create a better relationship between the customers, society and stakeholders. Today, a company's image can be completely improved by applying minor changes that benefit directly to the environment. A case study analyzed the application of eco-design in 30 companies (15 in France and 15 in Canada) within diverse industry sectors. The paper concluded that applying eco-design into their products and processes were reflected in the increase of sales rather than the decrease of costs applied in the production (Plouffe et al., 2011). This means that people today are more interested in buying products that consider and take action in reducing the environmental impact.

<u>Social Impact</u>

Concerns in the health of our environment are becoming a high marketing focus point, customers care about the environmental impact their purchases are causing. In 1989, 67% of the buyers were willing to pay 5-10% more just to assure the merchandise was more ecological than the competition, studies in 2001 determined that clients are willing to pay up to 40% more to obtain a eco-friendly product (Laroche, Bergeron, & Barbaro-Forleo, 2001). Although Laroche analysis is not recent, it can give us a bigger picture of what will happen in the future, "green" merchandise and publicity is on the rise, today, we care more about the environment than ever before. Companies should be making the extra effort to produce goods that harm our planet the least way possible.

This type of social behaviors is encouraging the industry to turn "greener", not only can they benefit from the manufacturing process, but also can increase their sales revenues by targeting most of the customer's mentality. However, this current ecological trend may tempt companies to modify or add anything "eco-friendly" to their products just so that they can sell it as a product that cares for the environment.

"For example, Procter & Gamble and Wal-Mart were publicly criticized for putting a green label on a brand of paper towels made of chlorine-bleached, unrecycled paper and packaged in plastic, simply because the inner tube for the towels was made of recycled paper." (Laroche et al., 2001).

2. 2. 6 *Additives or Composites*

As discuss previously, recycled plastics may receive diverse kinds of degradation due to many factors, to this, reused plastics may not be considered suitable for some uses given the fact that some mechanical or physical properties may be degraded.

There are diverse methods or upgrades we can use during the processing of recycled plastics in order to reach the qualities of a virgin polymers, some examples will be presented below (Vilaplana & Karlsson, 2008).

-Restabilisation of Recycled Plastics: Adding of phenols and hindered amine stabilizers que help protect the recycled plastic flakes, this will act as a protective coat against thermo-mechanical degradation during the melting process of re-obtaining post-consumer polymers (Vilaplana & Karlsson, 2008).

-Blending of Virgin Polymers: This practice is the most commonly used in the industry, basically the degradation of post-consumer plastics is compensated by the adding of raw flakes. Compatibilisation agents and re-stabilizers are used to improve the composite between virgin and used flakes (Vilaplana & Karlsson, 2008).

-Re-building Single Plastic Waste Streams: By using specific chain extenders (additives) in the specific process of extrusion, molecular weight is increased, therefore the chain length also grows, therefore, upgrading degraded post-consumer plastic (Vilaplana & Karlsson, 2008).

-Compatibilisation and Rebuilding of Mixed Plastic Waste: Recycled plastic normally has a low percentage of compatibility between them, to create a strong bond between the different polymers they must be compatible at certain characteristics. Non-reactive compatibilisers improve the adherence between two or more used plastics, reactive compatibilisers create a chemical reaction to create effective links between the components (Vilaplana & Karlsson, 2008).

-Addition of Inorganic and Organic Fillers: For this process to work, we need to apply compatibilisation methods using reactive groups. Inorganic fillers can be made of Calcium Carbonate or Calcium Silicate, organic fillers are made from wood fibers, cellulose residues and other organic components (Vilaplana & Karlsson, 2008).

2. 2. 7 *Using Recycled Plastic in Furniture*

The main purpose of this paper is to analyze and discuss the possibility of using recycled plastic as a component or key visual element in the manufacturing of furniture. Besides trying to find if plastic are an ideal material for furniture making, we also need to consider the social impact this reused material creates.

Furniture are desired items that complement our house aesthetically and emotionally, they complete our own interior common space (Postell, 2012). What better way to represent used plastic and create consciousness in our society that to use this recycled material in our daily objects, not only create a visual impact to the user but also involve the person with the furniture itself, a physical and emotional connection will be made.

The whole point analyzed in this paper is using a recycled material in a common object to promote and activate people's reaction. We need people to understand the current environmental situation, what better way to represent our plastic waste problem than to represent it in daily usable objects (furniture).

One of the biggest advantages of employing recycled plastics into furniture is the promotion of utilizing plastic in better and longer applications. Furniture are commonly used for several years, contrary to the short-term life of plastic packaging objects. A clear product example of this would be the "111 Navy Chair", a chair made from one hundred and one recycled Coca Cola bottles. "We've turned something many people throw away into something you want and can keep for a long, long time" (Hickman, 2010)

Furniture Design with Recycled Plastic

An easy way of creating a product that is eco-friendlier is to change or focus the design part. The choosing of the material that will be used for producing components in a furniture are a key part in the design process, the material that makes less damage to our environment should be the priority (Yüksel & Kiliç, 2015).

The first area that should be looked upon in design is the disassembly of the furniture itself, we cannot promote recycling of a product if the assembly itself cannot be easily disarmed to divide and classify the materials independently. Furniture should be though for remanufacturing after consumer use, this way the user itself can help in the process of reusing the material (Bogue, 2007; Hauschild et al., 2004).

Recycled plastic can be used in furniture, and most certainly can be beneficial, although special attention need to be focused in the application and quality of the recycled material used. Let's take for example that the mechanical piece that takes up the most stress during normal function could be made from wood and the more aesthetical parts or components that do not take up that much load could be assigned to recycled polymers. For example, a normal chair or stool, the legs could be made from solid wood and the actual seat could be made from recycled plastic flakes. Further structural tests and evaluations must be made to the furniture design to create the ideal choice that is both durable and pleasing to the future client.

Plastic versus Wood

Before considering recycled plastic as a usable material for furniture we need to compare its virgin or raw state versus the use of traditional and organic wood. Wood in furniture has been used for many years, however, furniture is manufactured in a variety of materials, in this paper we need to evaluate if polymers are a good option for this type of products. We are not mentioning aesthetic characteristics of both materials to make things easier, we are only analyzing physical and mechanical properties.

Plastic is increasing its production and variety of uses, today, we can see them in several furniture applications, it's more complicated to work with than wood, however, it's light, easy to paint, transport, clean and store, also, it can be worked almost the same as wood. Plastic can be used for transparency purposes, in some cases polymers can be more rigid than wood, given their popularity and massive production they are very low-priced compared to wood (J. Wang, Zhang, & Liu, 2009).

Polymers are being used so much in the furniture area that they have even developed a component called plastic lumber, this object can be made entirely out of recycled plastic or be a composite of plastic and wood waste. It's main purpose it to replace wood in some specific applications (outside furniture, flooring, paneling, walls, etc.). A study mechanically analyzed thermoplastics used in plastic lumber against regular wood lumber, they concluded that these specific polymers are very distant in in obtaining similar tenacity and strength values than those in wood. However, they saw that thermoplastics are most likely to work in situations where wood is compressed or tensioned perpendicular to the grain, conditions where this organic material is likely to fail (Dias & Alvarez, 2017).

METHODOLOGY

3. 1 TIME FRAMES

A simple Gantt chart (Chart 3.1) was created and applied to add some structure and organization to the project's time organization.

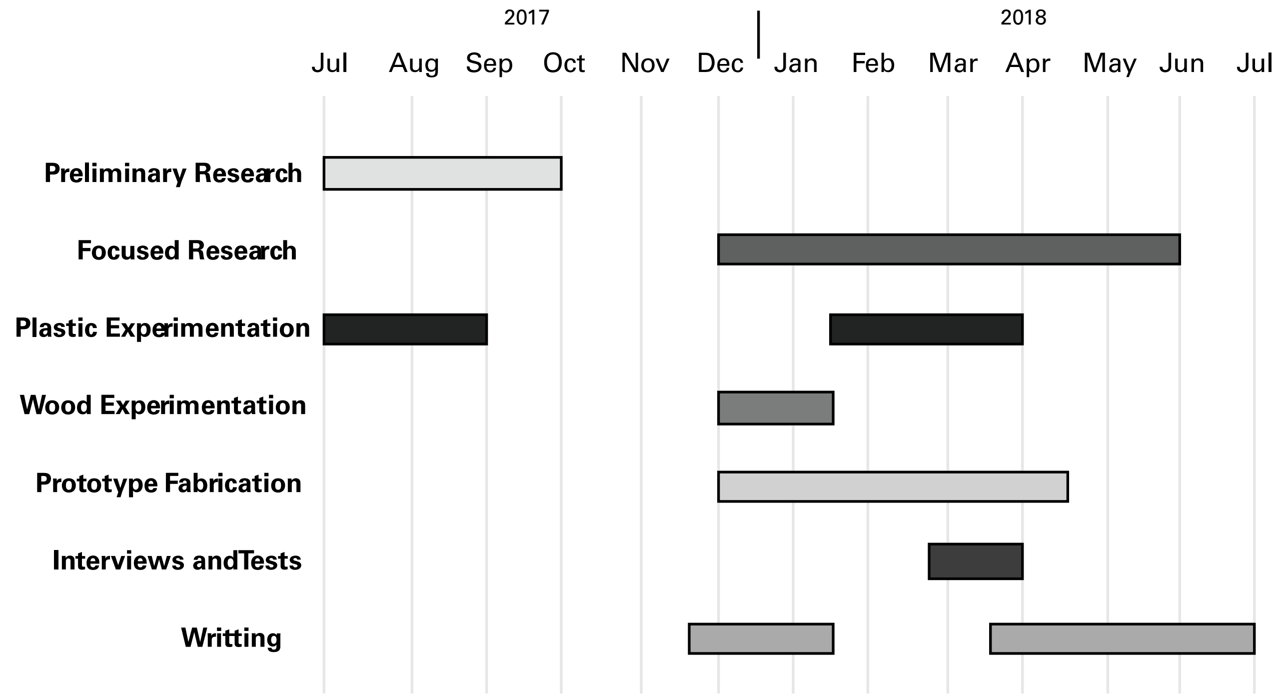


Chart 3.1 Gantt chart of project's time organization.

3. 2 DATA COLLECTION

3. 2. 1 Literature Study

A detailed bibliographic study was carried out to search published information useful to all the areas analyzed in this project. Obtaining information from research articles or projects with a correct revision is an important step to create a solid base for a product's design (Hanington & Martin, 2012) . Books, articles, reports, and standards from reliable sources were used as references throughout the elaboration of this research paper.

All the literature found was read digitally, the internet and the use of the reference organizer software Endnote® where great tools practiced in this research paper, they made the search process a quick and efficient task.

3. 2. 2 *Visual and Written Structure*

The arrangement of a thesis paper must be presented in an orderly and premeditated manner. It is important that the future readers can easily follow and understand the information throughout all the chapters. The physical structure, material organization, image usage, chapter methodology and page layout of this research paper was inspired by other thesis projects (Chen, 2016; Engström & Österdahl, 2011; Ghazal, 2016; Khalighy, 2015) that focused on product design.

3. 2. 3 *Experimentation and Observation*

Attentive observation and organized documentation of environments, people, products, events, object interactions, behaviors, and emotions should be applied during the observation process (Hanington & Martin, 2012). To learn from the mistakes made in the experimentation stage, a deep and meaningful observation is needed.

3. 2. 4 *Interviews and Tests*

Interviews and tests are a great tool to collect information and opinion from future users. A formal and structured interview must be made. Guidelines and rules are to be applied to create better and reliable results. If the interview scheme is designed correctly, useful quantitative information can be extracted that later can be statistically analyzed (Engström & Österdahl, 2011).

The author should create and direct the interview processes, this way, he/she can benefit with a direct observation and feedback process when analyzing the interviews react and behave with the presented objects or questions (Ulrich & Eppinger, 2000).

3. 2. 5 *Industry Visits*

Different industry companies were visited during this thesis project. They were of great help to understand how things are being made. The visits included a walk through the entire manufacturing process and a brief session of questions and answers at the end.

<u>Sorting and recycling company.</u>

Testing and experimentation was carried out with recycled thermoplastics. In order to have a controlled and large stock of raw material, a recycling

company was contacted. Daniel Morais S.A. was our provider concerning recycled polymers. A guided visit was granted to learn how they categorized and sorted out their plastics. They also informed us how the recollection system was managed in the north of Portugal, helping us understand how efficiently thermoplastics can be gathered and reused locally.

The company sold for a low price, fifty kilograms of shredded recycled thermoplastics (PET, PP and HDPE). With these pellets, most of the testing samples, prototypes, and final products were made.

<u>Recycled plastic lumber company.</u>

Extruplas is a Portuguese company that focuses on the manufacturing of recycled plastic lumber; in addition, they also create basic outdoor furniture such as: benches, beach walkways, trashcans, tables, and other outdoor public furniture. They offer circular, square and rectangular profiles with different standard lengths, their products are a composition of different recycled thermoplastics (PP, HDPE, PET and others) combined with diverse additives and protective coatings.

The guided visit was of great help in learning about the actual machines and processes utilized in the creation of products made entirely from recycled thermoplastics. The brief question/answer session helped us understand how recycled polymers behave the way they do. It was rewarding to know that they went through the same problems we had, while undergoing the experimentation phase.

<u>Low-production furniture carpentry.</u>

Even though we are using recycled plastic as our main material, we need to remember we are designing and creating furniture. For thousands of years these products are traditionally made from solid wood, today, they combine a great diversity of materials, even so, wood tends to be the most utilize material in furniture even today. Therefore, the importance of this traditional carpentry visit.

A small furniture carpentry was visited in order to have a basic view on how furniture are traditionally made, it is a small and old carpentry that has been making furniture out of solid wood for years. They practically do not use Ready-to-Assembles fasteners and rarely use woods derivatives (fiberboard, plywood, chipboard, or Medium-D`ensity Fiberboard [MDF]), they utilize a few machines and three active workers.

This visit was so educational, we learned the care and quality traditional furniture provide and why people are still willing to pay high prices for it. With all the new design styles and tendencies, this type of businesses are slowly disappearing, it is important to learn their methods and care for material quality so that we incorporate them into our designs.

3. 3 ANALYSIS

3. 3. 1 *Quantitative Results*

Measurable results were obtained and analyzed in several phases during this project.

In the case of the tests and interviews, both quantitative and qualitative data can be obtained depending on how they are structured (Engström & Österdahl, 2011). During the experimentation and prototyping stages it is very important to register all the learnings in a structured and organized manner, this way, patterns and constants can be denoted and applied in the final designs.

3. 3. 2 *Software Analysis*

Different types of computer analysis software where employed during the elaboration of this project.

Excel software (Microsoft Office®) was used to analyze all the information gathered from the interviews and tests and convert them into quantitative data. Graphs, charts, tables, and percentage values, were quickly created using this software.

Since this project focuses on the implementation of specific materials into a product's design, a materials software was required. CES Edupack® was the preferred option for this manner, since it possesses an extensive data base, and offers a user friendly interface.

Today, Computer-Aided Design (CAD) software has evolved in many aspects not only in visual 3D representations. They can help extract diverse data from the model itself (Chandrasegaran et al., 2013). In this thesis project, Solidworks® 3D software aided in obtaining mechanical and physical information such as, component and total assembly weight, mass centroid, maximum load capacity, impact resistance, balance limits, component interference, and geometry tolerance ranges.

3. 4 VISUALIZATION

3. 4. 1 *Charts, Graphs and Mind Maps*

Throughout this paper, you will see charts, graphs, and mind maps being used. These visual aids are often convenient to present information in an easy and clear manner, if used properly, they can explain in a clear way a complicated topic using less space than written words (Durbin, 2004).

When displaying quantitative information in charts or graphs it is important to display data as simply and clearly as possible (Few & Edge, 2008).

3. 4. 2 *Mood Boards*

Mood boards are very commonly used at the initial stage of a product's design, they are an easy way to brainstorm all different products, forms, colors, shapes, applications or any other category you need to visually explore. This image collage can be defined as : "Those assemblages of images and, less frequently, objects, which are used to assist, creativity and idea development in design activity." (Garner & McDonagh-Philp, 2001).

3. 4. 3 *Sketching*

A concept can normally be expressed as a sketch or drawing, they can show the object in different perspective and denote key features or characteristics (Ulrich & Eppinger, 2000). Sketching is a relatively simple and economic method to quickly visualize ideas and concepts. There are many forms and styles to use sketching in product design, it is a helpful tool throughout the entire design phase.

3. 4. 4 *Prototypes*

In this thesis project, prototypes represented one of the most important stages of the product's development. Making a real representation of a design efficiently helps visualize the object's flaws and virtues, something that no CAD software of sketching drawings can.

Prototypes are a crucial element through the elaboration of a product's design especially at an early stage (Hanington & Martin, 2012). Because we are working with recycled plastics, prototypes are of much help to learn and perfect the design's final form and manufacture.

Since we are designing a furniture object, full scale prototypes are of great importance in terms of ergonomic and handling experiences. Physically being able to test your product at real scale can give you a clear feedback of problems or details to correct or enhance.

3. 4. 5 CAD-Models and Renders

"Since the 1990s, computer-aided design (CAD) tools have had a significant impact on industrial designers and their work." (Ulrich & Eppinger, 2000). It is easy and comfortable way of visualizing the final shape and form of your design in through the help of 3D or CAD software. There are several different options available in the market, but they all attend the basic need of a 3-D visual representation of your design.

Three-dimensional software can help improve the communication and visual representation with the development team. They also detect and eliminate errors and interferences in a quick and easy manner compared to the manually generated sketches from a few years back (Cardaci, 1992). CAD software can help us visualize our products in many different shapes and colors, they are of great help when creating manufacturing blueprints of the model.

Solidworks® was the selected CAD software, so as to aid in during the product's concept and prototype elaboration. Detailed technical drawings will be created to facilitate the prototype's elaboration; in addition, it will also help foresee future component collisions or design errors.

To complement the CAD programs, a realistic visual aid software was implemented. A render or photorealistic image of the desired product was created to see the future outlook of the furniture. Renderings are commonly used to demonstrate the interaction of the product with the future user. They serve to observe the customer's reception to the proposed object (Ulrich & Eppinger, 2000). In this project, Keyshot® was the rendering system that helped create a visual simulation of the product's final aspect with its surroundings.

3. 5 MATERIAL DRIVEN DESIGN (MDD)

Materials election has been carried out in product design without change for many years. It is analytically driven by the constraints found along the selection procedure, it is considered to have the equal weight of other steps like: intentions, aesthetics, perceptions, processes and the design of the product (Ashby & Johnson, 2013).

Given the great importance of highlighting the use of recycled plastics in this project, a different design approach has been chosen. Material Driven Design (MDD) provides the material design approach we are searching for. This technique has been investigated and mainly developed by doctor Elvin Karana. The central idea is that the complete design process revolves around the material itself, which in this case, would be the recycled thermoplastics.

3. 5. 1 Introduction to MDD

MDD is a design technique that focuses or departs from the material as being the main promoter and medium of approach to fulfill the objectives and requirements of a given product (Pham, Eldukhri, & Soroka, 2011). This technique is relatively new, it is focused in dealing with new materials but it can also be applied with known components. This methodology has been applied in a wide variety of projects, for example, in the creation of organic composites like NeWool (Valentina, Camilo, & Stefano, 2016) or CapPurcino (Karana, Barati, Rognoli, Der Laan, & Zeeuw, 2015). Also, in engineering applications like 3-D printed textiles (Lussenburg, Van der Velden, Doubrovski, Geraedts, & Karana, 2014), and aeronautics (Tserpes, Ruzek, Mezihorak, Labeas, & Pantelakis, 2011). It even has been used as the main concept for a computer aided software that creates designs out of the selected materials (Bluntzer, Ostrosi, & Niez, 2016).

It is important to mention that each product, material, and manufacturing process varies from project to project that applies an MDD approach; therefore, it is expected that the designer itself modifies and changes the procedure to its advantage when seeking specific results (Karana, Barati, Rognoli, Der Laan, et al., 2015). In this project this procedure was not exactly followed as stipulated in the articles. It was modified to fit specific purposes.

Karana's approach was used with the intent of knowing through personal experiences the usage of recycled thermoplastics. It was not used as a method for designing the shape or model of the product itself.

MDD works with a simple four step method (Figure 3.1), the steps that were taken to embrace this technique will be explained in detail further ahead.

This specific design methodology was chosen for various reasons which are presented below:

-Modern and easy to follow.

-Knowledge or experience as a designer is not needed.

-The experimentation process starts at the first stages, with this, future problems are detected.

-No expensive machines, materials, tools or software are required.

-Very adequate for the application of recycled polymers.

-There is little information on how to work with recycled plastics, therefore, experimentation process is the best way to learn about future suitable applications.

-A deeper experience bond can be made with the product, different from the standard design strategies.

-The learning process is through experimentation and not theory, therefore, no deep or detailed previous knowledge is needed.

-With problems appearing during the experimentation stage, several manufacturing techniques may arise.

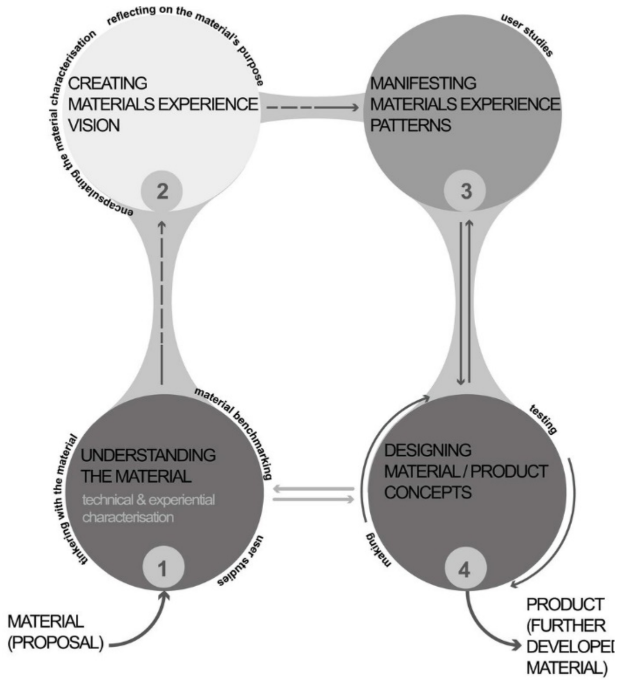


Figure 3.1 Steps and process diagram of Material Driven Desig.

(Karana, Barati, Rognoli, Der Laan, et al., 2015)

3. 5. 2 *Steps and Process*

Step 1: Understanding the Material: technical & experimental character

To create a better understanding of the material being used, there must be an experimentation process where certain characteristics are learned at a physical level. This step is of great importance specially when working with a material (recycled plastic) that is normally only manufactured in an industrial scenario. To obtain a better perception of the material it should be

tinkered and analyzed in four areas: emotional, performance, sensorial and interpretive (Giaccardi & Karana, 2015).

The process itself of creating samples was not the only form of experimentation, simultaneously, manufacturing processes were also analyzed. The integration of fabrication methods into the design stage is necessary in order to enlarge the capabilities and vision of the future product (Pham et al., 2011).

A small investigation of technical information on the materials analyzed needs to be made prior to the experiments. This will help as basic guidelines on how the material will behave in future tests.

Step 2: Creating Materials Experience Vision

In this step we need to summarize or make sense of all the learned experiences from step 1 and start thinking of a practical and functional contribution (Karana, Barati, Rognoli, Der Laan, et al., 2015). Focusing in recycled plastic, we need to know how are we going to provide purpose to this material in a social and environmental context.

To give a clear example in this manner, Lussenberg's paper "Designing with 3D printed Textiles", can be utilized. The author mentions how changes in the fashion area are leading into rapid disposal of textiles; thus, slow fashion arises to make garments that will be used on a long term purpose (Lussenburg et al., 2014). This type of factors must be considered when analyzing future utilization of such materials. Real-life variables must be considered so that the material's properties can fulfill actual needs.

Following the steps of the MDD methodology several questions need to be answered in order to give a valid and objectified purpose to the material being used. Four different areas, environmental, experience, functional and application, need to be studied to better understand the necessities and requirements that recycled plastics should fulfill in this project.

Detail regarding these questions will be discussed further ahead, and, when answered, the unique purpose of the material represented in an object may be solidified (Karana, Barati, Rognoli, Der Laan, et al., 2015). In the recycled material context, it is crucial to transmit the importance of recycling to the user through the product itself, this will be one of the main messages that the furniture should pass to the future customer.

The desire for better functionality in products, the globalized economic growth, and the free trade between markets, create a big influence in product design (Ashby & Johnson, 2013). Since we are working with new implementations of a known product, it's important to explore what objects are currently being used with similar material characteristics (Karana, Barati, Rognoli, Der Laan, et al., 2015). A brief and intense investigation of similar products available in the market, needs to be made to create a better vision of the user's actual needs and preferences.

Step 3: Manifesting Materials Experience Patterns

The first thing we need to do in this step is to find two key words or meanings that best describe our final product. (Karana, Barati, Rognoli, Der Laan, et al., 2015) . Target user, social background, environmental impact, emotional attachment, and expected interaction were some of the aspects that were taken into consideration when analyzing the two word that best described this specific furniture.

A complementary process that will help us find this specific experience patterns is the Meaning Driven Materials Selection, developed and explained by Karana .This process is made so that the designer can learn how the users attach specific meanings to the materials presented. These meanings will be focused on the key words previously selected (Karana & Hekkert, 2010). In this step, three different tests will be applied in order to obtain information on certain tendencies or focus on given recycled thermoplastic samples.

Step 4: Designing Material/Product Concept.

In this step the final design should be created from the material's specific characteristics and attributes. The demand of products with new and modern materials is increasing, since these requirements have changed, the form and geometry should change as well. Saying this, the design or shape of the final product should be driven from the material itself (Bluntzer et al., 2016).

In this project, step four, was not implemented, the geometry and layout were already defined by other contributing factors (manufacturing limitations, personal factors, easiness, and social trends). Therefore, this specific stage was not rather fully performed, rather, a similar process was carried out during the interviews in step three.

3. 5. 3 *Interviews and Tests Specifications*

Meaning Driven Materials Selection (MDMS)

Steps and methods were taken from (Karana, Barati, Rognoli, Der Laan, et al., 2015) and (Karana, Hekkert, & Kandachar, 2010), with modifications made to satisfy the project's necessities.

The first test is made with twenty-seven recycled plastic samples, with different shapes, textures, colors, material and manufacturing processes. The intention of using many different recycled samples is to observe if there is a clear attraction to a specific object even if the abysmal differences between them generate a distraction.

Participants were asked to analyze the samples based on colors, patterns, texture, and physical characteristics. All objects had different shapes which obviously create an impact on the results; however, due to the different manufacturing processes, it was difficult to produce samples with same forms or geometries. Presented below are the instructions to perform the first test.

1. All samples are presented, and three minutes of free time is given to inspect and analyze the samples.

2. Once presented, participant is asked to choose the one that he/she prefers (without explaining or giving any kind of details).

3. Participant is asked to select the material that relates the most to given keyword.

4. Participant must provide a picture or image of a product/object that represents the given keyword.

5. Interviewee must explain in detail why that material was chosen and fill out the sensorial scales.

6. Steps 2-5 are repeated with the second keyword.

Directions or rules to be followed by interviewer:

-Explain to the interviewee that this is a test made for academic purposes and that all questions and information, will be given at the END of the interview.

-Interviews must be recorded unless prohibited by interviewee (NEED to ask before beginning tests).

-All comments and feedback are to be registered and analyzed.

-Besides the questions being asked, there should be NO interaction between the interviewer and the interviewee while the tests are taking place.

-A explanation of the test, project, materials and objects must be done at the end of the test.

Finishing Test

The intended result from this test is to know the public's preference to a specific type of finishing in recycled plastics. The object should contain different finishes, all sides must have the same dimension, shape and color (ex. cube) to try and avoid any distractions that might alter the visual or tactile detailing of the different surfaces. Presented below are the instructions to perform the second test.

1. The object is presented and the participant is asked to choose the face of the object that he/she prefers (without explaining or giving any kind of details).

Directions or rules to be followed by interviewer:

-Objects that are presented must have similar color and form, so as to focus only on the finishing of the material.

-When explaining the final design, pictures, renders, prototypes or any other visual representation, should be shown to the interviewee.

-The rest of the indications are the same as test 1 (MDMS).

Shape test.

When developing the stool's design, many different shape variants can arise. Taking advantage that an interview process will be made, two of the final forms will be compared and introduced to the participants. The purpose of this test is to see if there are clear preferences to a given geometry, this provides more validation to the final design. Presented below are the instructions to perform the third test.

1. Images, renders, and prototypes, from the two design variations are showed to the user (no additional information should be given).

2. Participant is asked to pick one option that he/she prefers with no further explanation.

3. A brief explanation between the differences of the two designs is given, the interviewee is asked again to choose the shape he/she prefers based on the previous explanation.

Directions or rules to be followed by interviewer:

-In step three, explanation between the two designs should be regarding to functionality and not aesthetic, visual, or manufacturing aspects.

-The rest of the indications are the same as test 1 (MDMS).

DEVELOPMENT

4.1 DEFINITION OF PRODUCT

4.1.1 Furniture

As mentioned in chapter, packaging products are the largest and most common plastic usage, thus, the amount of waste is becoming a big problem to our environment. This project intends to highlight the importance of plastic recycling. We need to design and create objects that reutilize this problematic material. We believe that a good way to represent a recycled product is one that promotes a long consumer use in comparison to the short life of current packaging applications. If the nature of plastics is to last for several years. Why not use this characteristic to our advantage?

Given the nature of furniture, its dimensions and materials used, they are normally seen as an object that will last for years if not decades (Leslie & Reimer, 2003). Furniture can be ideal examples to combined with recycled plastics, they create a valuable contrast to the short-term life of common plastic products.

“Furniture becomes an extension of the body, a vehicle for self-display and comportment” (Molotch, 1996). If we want to promote and communicate the importance of making products with recycled plastics, we need to design an object that connects in several forms with the user. It needs to make a physical and emotional bond with the future enjoyer, furniture products can be considered to have these types of virtues.

Furniture has been used for many centuries within different cultures and societies. It’s design is a social science that has been applied and utilized for many years and utilizes many different disciplines (Postell, 2012).

After several brainstorming sessions, we decided that a stool would be the furniture category to be designed and developed. The stool is one of the simplest and oldest form of portable human support (Postell, 2012). The object involves all the physical and mechanical challenges since it must support an average human body weight. Also, given the average dimensions, it is easy to make a real scale prototype since it is not as big or complicated as a table or a closet.

As mentioned in previously, the implementation of recycled plastics into the furniture's design will be the priority of this research paper. However, due to aesthetic, social trends and visual aspects, plastic will not be the only material applied into the product's components. After an evaluation in actual and modern furniture, we decided that wood would be combined as a complementary piece in the stool's design. This was mainly due to its traditional background throughout furniture applications and its appealing look when combined with plastic.

4. 1. 2 *Multi-Functional*

This product will not be limited to any nationality, culture or society, it will be designed with a global perspective. One of the biggest challenges that affect modern furniture design is the current decrease of living space. Residencies are getting smaller especially in crowded cities, this direction is creating a new need in the furniture industry. A report made by Urban Land Institute (UrbanLandInstitute, 2014) concluded that in the U.S.A there is a noticeable decrease in the living space units (Chart 4.1). Studio and one-bedroom apartments construction is on the rise and micro apartments are becoming a trend in the housing market (Chart 4.2).

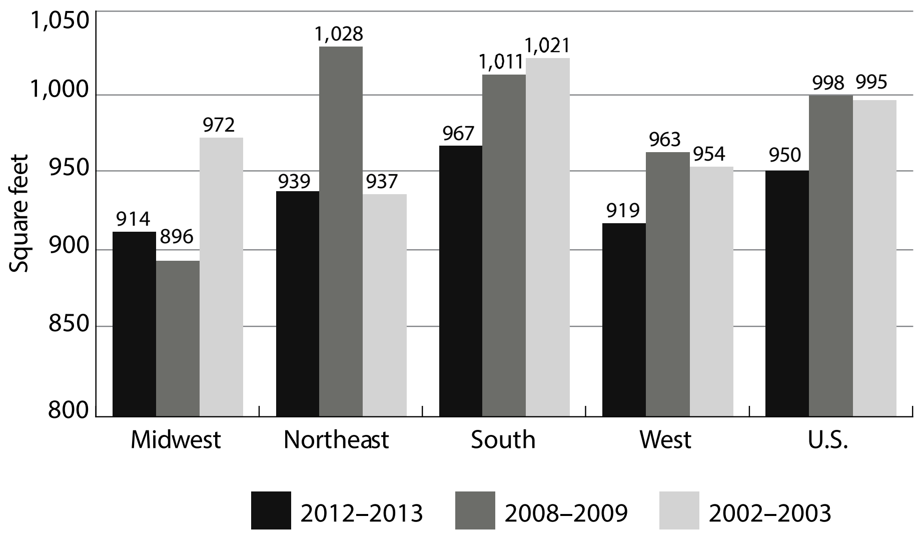


Chart 4.1 Average living unit size (square feet) in the U.S.A

(UrbanLandInstitute, 2014)

With size becoming the biggest problem in modern housing, transformable furniture may be one way to solve the current space problems (S. Wang, 2013). The amount of furniture that will be used will be limited by the available space, thus, these products will need to serve in more than one purpose or activity. "Furniture has come to more closely resemble clothing in terms of the need for spatial mobility and flexibility" (Leslie & Reimer, 2003).

Multiple function furniture typically change their form and functionality

through an integrated mechanism or, using removable or interchangeable parts. It is important that the added components are light and easy to remove, if the furniture needs to be modified constantly, small amounts of energy must be applied by the user in order to avoid future health problems (ÖZÇELİK & KAPROL, 2016).

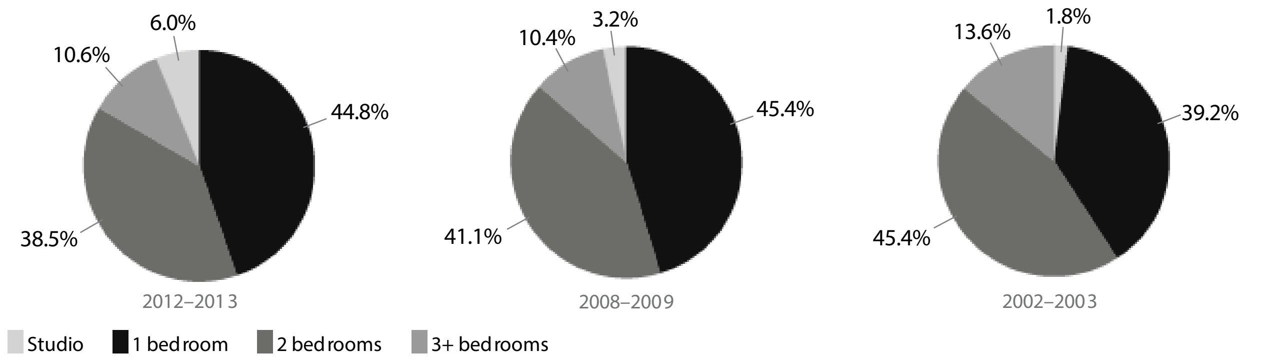


Chart 4.2 Bedroom type built during given cycles in the U.S.A

(UrbanLandInstitute, 2014)

When designing a multi-functional furniture, it can easily become a very complex and structured product, therefore, in this thesis we will try to keep the object as simple as possible. The additional functions must be well defined and cannot have too many alternative purposes, secondary features cannot interfere with the main objective of the object, if these variables are ignored, the furniture may become inefficient (ÖZÇELİK & KAPROL, 2016).

There are diverse characteristics that can transform a simple furniture into a multi-functional object. Modular, stackable, movable, flexible, foldable, expandable, removable, and joinable may be some of the attributes that are considered to constitute a multi-functional furniture (Figure 4.1). Careful analysis will be applied to design a multi-functional efficient furniture. In the case of our project, the primary objective will be to as a sitting stool and the added functions shall not interfere with this previously mentioned action.

Figure 4.1 Example or diverse multi-functional furniture.

In our project's vision, the furniture should not suffer any type of physical change or adaptation when being used with the additional features. In Figure 4.2 we can see some clear examples of multi-functional furniture that do not compromise the physical efficiency or structure to fulfill a supplementary function.

Figure 4.2 Examples of simple multi-functional furniture.

With an analysis of the current stools in the market and the need to implement multi-functionality, we established that our stool should work as a

side table (Figure 4.3) as a complementary feature. If the dimensions are correct, the stool itself can serve as both a seating device and a small table. If it can withstand the weight of a person, it should be able to support simple household items. The only key aspect we need to enforce, is making sure the seating surface is completely flat. This may affect the ergonomic integrity of the product; however, it will be fulfilling the two different needs.

Figure 4.3 Different side table uses and applications.

Another feature that was considered was the integration of a drawer system into the stool. Although it was a nice added characteristic, it meant adding more components, therefore, it was discarded due to its added complexity.

Besides global needs, anotherpersonal situation was considered. Currently living in a small apartment, the living room contains a small dining table, working desk, two chairs and a sofa. The lack of chairs or seating objects, forced guests to stand or sit on the floor. Even if stools where added, there was no space to store the stools when they were not being used. With these personal experiences and the current tendencies in living spaces we found the need to make our furniture easy to dismantle and store.

Figure 4.4 Simple shape modular stools.

Most stools can be used as a seating device and a side table, to fulfill the current living space demands, we needed to go beyond the common applications. We added yet another multi-function to our stool, to avoid complexity in our design we came up with a modular and simple solution. The joining or gathering of several stools would create a coffee table (Figure 4.4), this is not a new characteristic, but it complies to our project's needs.

The stool needs to be simple and visually independent, it must be aesthetically designed as a single member; however, when joined with several other identical objects, a new and attractive product emerges. The furniture must function and appeal to the user as both a single and multiple system.

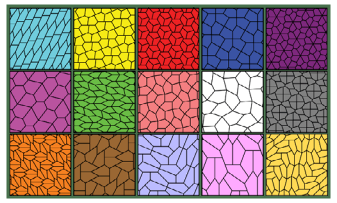


Figure 4.5 Fifteen different pentagon tilings.

After reviewing several existing examples, we chose to use the mathematical tiling technique as our design guideline. The joining or modular feature we are looking for is called "tiling". According to the Oxford Dictionary, from a mathematical point of view, tiling is "a way of arranging identical plane shapes so that they completely cover an area without overlapping." (OxfordDictionaries, 2018).We are using a specific type of tiling which is composed only of convex pentagon shapes. Fourteen different tiling convex (Bagina, 2004) pentagons have been discovered , with the adding of a new one recently, this makes up in total for fifteen possible patterns (Figure 4.5).

Each type has its own set of rules or variables, this means that the angles can be changed but must remain inside the established conditions (Figure 4.6). After visually inspecting each pentagon tile, we chose to use the Type 8 (Figure 4.7) as our design guideline for the seat's shape.

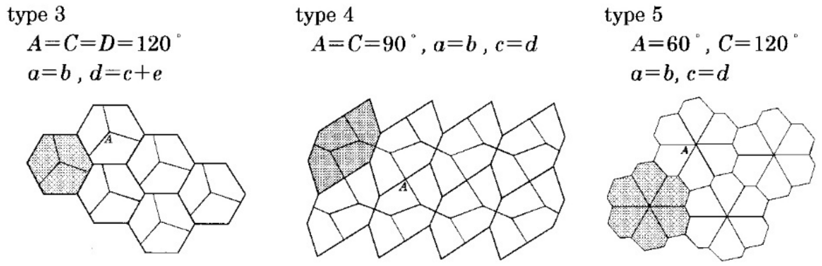


Figure 4.6 Pentagon tiling formulas that limit the geometry and size-relation, example: types three, four and five

(Sugimoto & Ogawa, 2000)

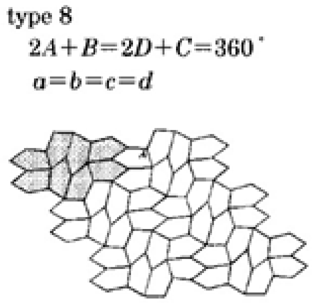


Figure 4.7 Formula for pentagon tiling type "8".

(Sugimoto & Ogawa, 2000)

4.1.3 *Eco-design*

This stool must have a strong eco-design background, besides using recycled plastic as our main sustainable characteristics, we will attend to other environmental aspects as well. Throughout the entire design and development phase, eco-design will be applied to the fullest; and if not possible, future improvements will be noted.

All the information analyzed and summarized in chapter 2 helped us create guidelines and characteristics to follow so that our product's design can be sustainably efficient.

4.1.4 *RTA (Ready-to-Assemble)*

Easiness in assembling and disassembling can be considered a quality of a multifunctional furniture. This stool will have certain attributes added to fulfill the user's current needs. Ready-to-assemble (RTA) furniture is considered a type of furniture that utilizes numerous kinds of fasteners (Figure 4.8) instead of the traditional glue joining technique. These types of furniture are widely use in the market and can be considered as a new (compared to gluing techniques) method of joinery (Simek, Haviarova, & Eckelman, 2010; Uysal, 2014).

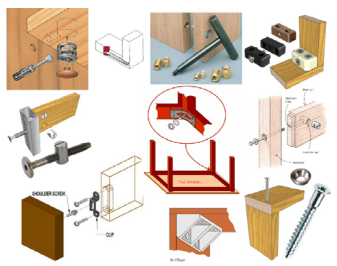


Figure 4.8 Different types of RTA joints.

Although RTA joints are not as strong or resistant as compared to using glue methods (Haviarova & Eckelman, 2014; Uysal, 2014)) there are several advantages of applying this modern joining techniques into furniture. Some of the advantages of applying RTA method into furniture design are presented below.

-creates the dismantling an easy process, therefore, components can be reused, recycled and remanufactured

-minimum tools required for installation

-reduces transportation costs (flat pack)

-fasteners facilitate integration of different materials

-reduces environmental impact

-facilitates maintenance

We want to create this stool as an easy object to assemble/disassemble for storing purposes. Here specifically is where RTA can help us design the best possible solution for this pre-established condition. Screwing the legs with bolts, making special inserts and even hinges, were considered at early design stages.

This previously mentioned joining methods were discarted at earyl stages. We wanted to maintain the number of components to a minimum. Also, following the eco-design guidelines mentioned earlier (sub-section 2.1.4), the less different type of materials used in the product, the better. With these constrains in mind, we decided to integrate the joining technique into the stool's legs themselves. The end part of the legs should be adapted so that they can also function as connectors. Conic ends, magnets, male-female screws, and bushings were considered as viable options.

After analyzing manufacturing methods, mechanical characteristics and aesthetic conditions, we concluded that the stool's legs would screw themselves inside of the stool's seat. The legs would have a male thread, while the seat would contain the female threads, this way, no tools would be needed to assemble/disassemble.

4.1.5 *Definition of Characteristics and Attributes*

There are several qualities that where pre-defined in the creation of this stool, that can and will be modified throughout the entire creation of this thesis. These aspects are presented below:

Product: Furniture

Background: Intended for international use

Added features: Eco-efficient, multi-functional, RTA

Other functions besides stool: Side table and coffee table

Aesthetic factors: Simple

Materials: Recycled plastic and wood

Prototype manufacturing method: Restricted to the faculties' installations

*Other variables like price, form, colors, dimension, manufacture and materials will be evaluated and discussed further ahead.

4. 1. 6 Order of Priorities

Since there are various existing concepts and design areas that are being studied and employed into this project, we need to set an order of priorities that cannot override each other so that the product's design can have an efficient and fluid progress.

Important objectives to bear in mind:

-Implementation of recycled plastic in furniture is the main concept of this project.

-There are no limits in what kind of recycled plastic should be used.

Order of priorities:

1. The product must be a furniture.

2. Recycled plastic should be employed as the main component of the design.

3. Design for reuse, recovery and recycling.

4. The only material employed that is not biodegradable should be the recycled plastic.

5. The furniture product must have at least one more function from its original purpose.

6. From a general point of view, the product must be simple.

7. Ergonomic studies applied to the furniture must be of global scale.

8. Design for easy assemble/disassemble.

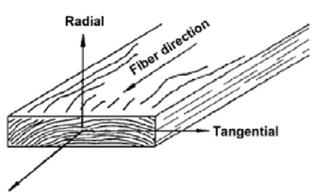


Figure 4.9 Orthotropic force axis in respect to the grain direction.

(Green et al., 1999)

4.2 MATERIAL

As mentioned in section 3.5, this project's design will be based and focused on the use of specific materials. Before analyzing the materials through MDD techniques, it is necessary to do some basic investigation of all the materials employed. When evaluating physical, chemical and mechanical properties, the material's virgin state (without additives, coatings, fillers or

compounds) will be used to avoid confusions and facilitate a better comparative analysis.

"Materials selection should be taken into account from the early design phases in order to have an impact on the product life cycle cost and to support the conceptualization." (Veelaert, Ragaert, Hubo, Van Kets, & Du Bois, 2016)

Most of the physical and mechanical information of the materials presented in this section were retrieved from the software CES Edupack® .

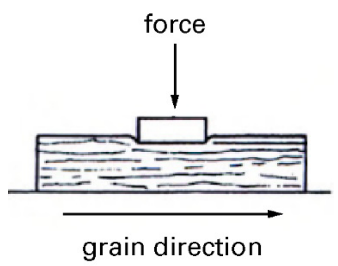


Figure 4.10 Compression force being applied perpendicular to the wood's grain direction

(Stalnaker & Harris, 1997)

4. 2. 1 Wood Technical Information

Since recycled plastic needs to be the focus of attention in this product, wood cannot be utilized in the stool's seat, therefore, wood will function as the stool's legs.

Since wood is an organic material, every sample or piece analyzed can be slightly different due to is organic structure, this makes it difficult to analyze it from a mechanical point of view. Wood is considered an orthotropic material, this means it behaves autonomously and uniquely in three different directions (Figure 4.9) or perpendicular axis (Green, Winandy, & Kretschmann, 1999).

Since wood will be applied in the stool's legs it is very important to take notice of the wood's grain direction. Wood's ability to withstand forces of compression perpendicular to the grain (Figure 4.10) are extremely low when compared to a parallel position (Table 4.1) (Doyle & Walker, 2007; Green et al., 1999; Stalnaker & Harris, 1997).

Table 4.1 Maximum compression values (kPa) from several different woods; parallel (green) and perpendicular (red) to the wood's grain

(Green et al., 1999).

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity[c] (MPa)	Static bending: Work to maximum load (kJ m⁻³)	Impact bending (mm)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)	Side hardness (N)
Hardwoods											
Alder, red	Green	0.37	45,000	8,100	55	560	20,400	1,700	5,300	2,700	2,000
	12%	0.41	68,000	9,500	58	510	40,100	3,000	7,400	2,900	2,600
Ash											
Black	Green	0.45	41,000	7,200	83	840	15,900	2,400	5,900	3,400	2,300
	12%	0.49	87,000	11,000	103	890	41,200	5,200	10,800	4,800	3,800
Blue	Green	0.53	66,000	8,500	101	—	28,800	5,600	10,600	—	—
	12%	0.58	95,000	9,700	99	—	48,100	9,800	14,000	—	—
Green	Green	0.53	66,000	9,700	81	890	29,000	5,000	8,700	4,100	3,900
	12%	0.56	97,000	11,400	92	810	48,800	9,000	13,200	4,800	5,300
Oregon	Green	0.50	52,000	7,800	84	990	24,200	3,700	8,200	4,100	3,500
	12%	0.55	88,000	9,400	99	840	41,600	8,600	12,300	5,000	5,200
White	Green	0.55	66,000	9,900	108	970	27,500	4,600	9,300	4,100	4,300
	12%	0.60	103,000	12,000	115	1,090	51,100	8,000	13,200	6,500	5,900
Aspen											
Bigtooth	Green	0.36	37,000	7,700	39	—	17,200	1,400	5,000	—	—
	12%	0.39	63,000	9,900	53	—	36,500	3,100	7,400	—	—
Quaking	Green	0.35	35,000	5,900	44	560	14,800	1,200	4,600	1,600	1,300
	12%	0.38	58,000	8,100	52	530	29,300	2,600	5,900	1,800	1,600
Basswood, American	Green	0.32	34,000	7,200	37	410	15,300	1,200	4,100	1,900	1,100
	12%	0.37	60,000	10,100	50	410	32,600	2,600	6,800	2,400	1,800
Beech, American	Green	0.56	59,000	9,500	82	1,090	24,500	3,700	8,900	5,000	3,800

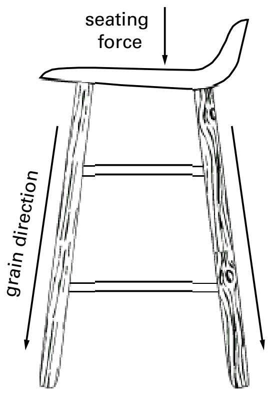


Figure 4.11 Grain direction perpendicular to the floor and parallel to the seating compression force.

Based on this information, the stool's wood grains need to be perpendicular to the floor, so that when someone sits on it, the force distributes in a parallel direction to the wood's grain (Figure 4.11).

Besides wood being an orthotropic material, there are a vast number of variables that may affect its physical and mechanical behavior when under stress. Moisture, cracks, nots, temperature, age, insect damage, plagues and even bird pecks may affect the wood's efficiency to withhold external forces (Green et al., 1999). The damage that was done during the tree's natural course of life cannot be changed, however, to avoid further damage, additives, coatings and sealers may be applied to protect or at least slow down nature's constant deterioration.

Choosing the type of wood

There are a lot of commercially available woods in the market, to choose the adequate one for our project we need to consider several aspects. Although it is difficult to find a specific wood that can fulfill all of our needs, the one the complies best will be chosen. In Figure 4.12 we can see the factors that were considered when choosing the adequate type of wood.

In wood terms, trees can normally be divided into two basic groups, hardwood and softwoods, hardwood trees have a thicker and shorter cell wall. This is the biggest factor as to why these wood types are more dense and mechanically superior (Green et al., 1999).

Choosing of wood

Physical Properties	**Ecodesign**	**Mechanical Properties**	**Other**
low-med density	NO composites	easy machinability	availability
bright colors	Resistant to weather without additives or coatings	resistant high impact	low-med price
aesthetic		strong	
		able to make thread	

Figure 4.12 Factors involved in the selection of wood.

Another important factor to consider is the usage of natural woods instead of its derivatives (plywood, MDF, particle board, fiber wood, laminated veneer and 3-ply). Natural wood is better for recycling purposes, are easier to work with, and tend to have better aesthetical characteristics.

With the help of the software CES Edupack® we narrowed the selection of woods, by applying diverse limits to make the process easier. The character-

istics that needed to be fulfilled are shown below.

FILTERS & LIMITS OF WOOD SELECTION

Composition overview

Form: Bulk material, Foam or particulate

Material family: Natural

Base Material: Wood (hardwood)

Composition detail

Wood: 100%

Price

Maximum: $3 USD/kg

Recycle and end of life

Downcycle: YES

Landfill: YES

After applying these filters into the materials software, we ended up with twenty-five different types of wood that fulfilled our specific needs (Figure 4.13). Thanks to globalization, it is relatively easy to buy any type of wood from anywhere around the world, however, this is not the best option when trying to create an efficient sustainable product. Thanks to the European Union, trade within European countries have become more efficient, thus, Europe will be considered as local source of wood in this project. In Figure 4.13 we highlighted in red boxes the trees that are not native within Europe.

CES 2017 EDUPACK

Alder (*Alnus Glutinosa*)
Ash (*Fraxinus Nigra*)
Aspen (*Populus Tremuloides*)
Basswood
Beech (*Fagus Sylvatica*)
Birch (*Betula Alleghaniensis*)
Butternut
Chestnut
Cottonwood (*Populus Balsamifera*)
Elm (*Ulmus Americana*)
Hackberry
Hickory (*Carya Aquatica*)
Honeylocust
Hornbeam
Locust
Magnolia (*Magnolia Acuminata*)
Maple (*Acer Macrophyllum*)
Oak (*Quercus Robur*)
Poplar
Sassafras
Sweetgum
Sycamore
Tupelo (*Nyssa Aquatica*)
Willow (*Salix Alba*)
Yellow-Poplar

Figure 4.13 List of hardwoods left after applying limits and filters in CES Edupack software. Highlighted in red are the wood types not native in Europe.

Using only European woods, we ended with ten different types: alder, ash, aspen, beech, birch, hornbeam, maple, oak, poplar and willow. Since this project is focused on the use of recycled plastic, wood is considered a complimentary component, therefore, we are not experimenting with different wood types. The final wood to be used as the stool's legs needs to be selected from this selection.

From the mentioned European woods, we will choose the wood with the best price, availability and mechanical characteristics. Since the wood will be used as part of the stool's structure, we will filter out the ones that have the worse compressive strength values. Since we are going to thread the endpoints of the wood legs to screw them at the base of the seat, the denser the wood, the better quality of the thread can be made. A comparison chart between density and compression strength was made to analyze the results (Chart 4.3), the best solutions are delimited by the red area.

Chart 4.3 Compressive strength vs density comparison chart.

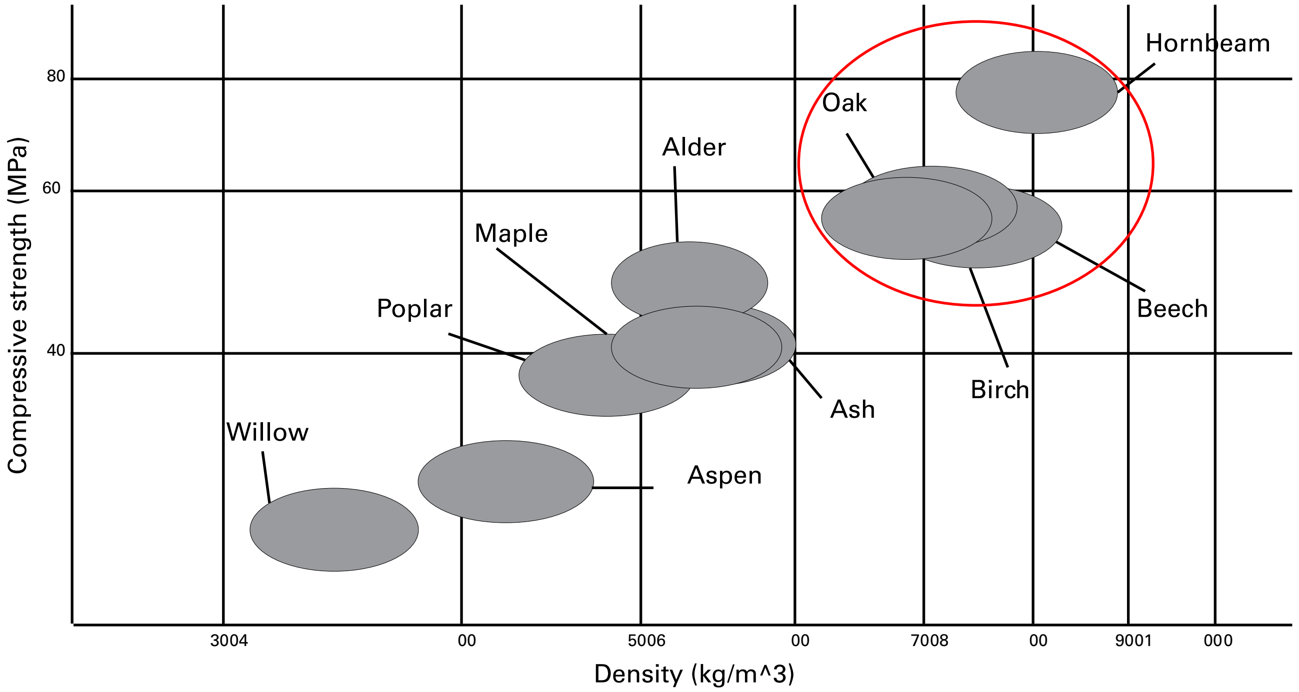


Figure 4.14 Samples of oak and beech wood.

In this case (Chart 4.3) Hornbeam would be the best choice for the stool's legs, however, in this project, availability and price are of great importance. Here in Porto, Portugal, Hornbeam and Birch are not commonly used woods, therefore, they will be discarded because the price is much higher than the other two options. Oak is not really within the aesthetic bright visual appearance we are looking for (Figure 4.14). In addition, after a quick visit to several woodshops, we realized that oak was a little bit more expensive than beech. In conclusion, we will select beechwood as our final choice.

4. 2. 2 *Thermoplastic Technical Information*

In this sub-section, we will analyze plastic's physical and mechanical characteristics as a viable material for furniture use. In the 1960s, plastic was still considered a new material, despite the large investment costs in the molds and machinery. The advantages that plastic had over the traditional materials were so great, that it has changed the furniture industry forever (Lawson, 2013).

Polymers being a man-made invention was created to be easily manipulated, thus, it has many advantages over other traditional materials (wood, metal, ceramic, etc.). Plastics have substantial benefits in terms of their low weight,

durability and lower cost relative to many other material types (Andrady & Neal 2009; Thompson et al.2009a).(Hopewell et al., 2009).

Choosing the type of thermoplastic

The decision of what recycled thermoplastic to use in the stool's seat was determined during the MDD's steps 1 and 3 (sub-section 3.5.2). Even though this unique methodology had a great impact on the choosing of plastic type, all the thermoplastics were previously scientifically studied.

Material availability, mechanical properties, physical properties, manufacturing easiness and health issues were the variables that helped narrow down the materials to be analyzed during the MDD process. The same process that was carried out with wood was applied with plastics. A simple analysis of the wanted characteristics was made (Figure 4.15) to simplify the selection.

Choosing of thermoplastic

Physical Properties	**Ecodesign**	**Mechanical Properties**	**Other**
low-med density	NO composites	easy mold compression	availability
aesthetic	NO fillers or additives	resistant high impact	resistant to household cleaning products
	recyclable	strong	
		able to make thread	

Figure 4.15 Factors involved in the selection of thermoplastics.

Even if not mention in figure, the first variable we are analyzing are the health issues, PVC and nylon were automatically discarded due to the toxic fumes that can be released during the heating or burning of these plastics. When burned, PVC releases hydrogen chloride (HCI) and Nylon hydrogen cyanide (NHC) (Stec, Hull, Lebek, Purser, & Purser, 2008), both dangerous to human health.

One of the biggest factors that will affect the selection of thermoplastics will be the availability, since we are applying recycled plastics, common thrown away plastic products (bottles, food containers, straws, bags, disposable kitchenware, etc.) will have priority.

With the help of the software CES Edupack® we narrowed the selection of thermoplastics, we used several limits to make the process easier. The characteristics that needed to be fulfilled are presented below.

FILTERS & LIMITS OF THERMOPLASTIC SELECTION

Composition overview

Form: Bulk material, Foam or particulate

Material family: Semi-crystalline and amorphous thermoplastics

Filler/reinforcement: None

Filler reinforcement form: Not applicable

Additive: None

Composition detail

Polymer: 100%

Processing properties

Polymer injection molding: Acceptable or excellent

Polymer thermoforming: Acceptable or excellent

Durability (household cleaning products)

Weak acids: Acceptable or excellent

Weak alkalis: Acceptable or excellent

Recycle and end of life

Recycle: YES

Downcycle: YES

Landfill: YES

After applying those filters in the materials software, we ended up with twenty-three thermoplastics that fulfilled our specific needs (Figure 4.16). Since plastic availability can differ by location, it is very difficult for a software to have this as a secluding variable. In Figure 4.16 we highlighted in green the most common thermoplastics available at landfills, trash bins or industrial waste containers. They are also among the most common recycled plastics.

CES 2017 EDUPACK

COC (general purpose)
COC (heat resistant)
COC (high flow)
PC (copolymer, heat resistant)
PC+PET (general purpose)
PCTG (unfilled)
PE-HD (low/medium molecular weight)
PE-LD (molding and extrusion)
PET (unfilled, amorphous)
PETG (unfilled)
PMMA (heat resistant)
PMMA (molding and extrusion)
PMMA+PC (unfilled)
PMP (general purpose)
PP (homopolymer, clarified/nucleated)
PP (homopolymer, high flow)
PP (homopolymer, low flow)
PP (random copolymer, clarified/nucleated)
PP (random copolymer, high flow)
PP (random copolymer, low flow)
PS (general purpose, 'crystal')
PS (heat resistant)
PSU (extrusion and injection molding)

Figure 4.16 List of thermoplastics after applying limits and filters in CES Edupack software. Highlighted in green, are the recycled thermoplastics easily available.

We have narrowed down our thermoplastic selection to five polymers: PET (Polyethylene terephthalate), PS (Polystyrene), PP (Polypropylene), PE-HD or HDPE (High-Density polyethylene) and PE-LD or LDPE (Low-Density polyethylene). These will be the plastics that will be tested and experimented in the MDD steps. Even if the final thermoplastic will be selected during

in the MDD section, simple scientific comparisons will be made to have a boarder knowledge on the selected materials.

To obtain more information regarding this previous thermoplastic selection, we need to analyze these materials when applied into furniture products. A stool is a very common object that may be regularly tipped over and impacted with other objects (more common that a closet, table or a bed); in addition, this simple furniture tends to be moved around quite often, thus, it cannot be a heavy object. For these common issues, we created a comparison chart that analyses the impact strength versus the density of the filtered thermoplastics (Chart 4.4).

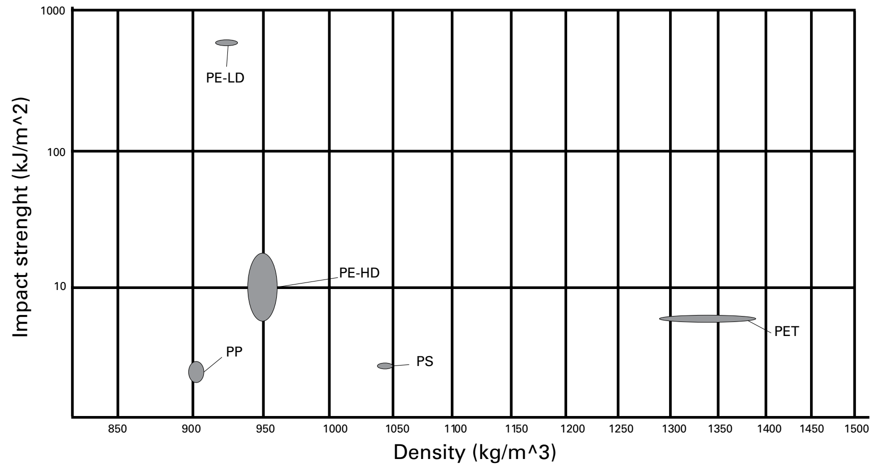


Chart 4.4 Impact Strenght vs Density comparison chart.

From a mechanical point of view, the upper part needs to withstand the compressive force being applied by the user's weight without any permanent deformation. In Chart 4.5 we can compare the different compressive strength values from the selected thermoplastics.

The prototypes, experiments and final products will be manufactured without the use of heavy machinery. We need to keep in mind that when working with plastics, at some point we need to apply pressure to create the desired final shape. Chart 4.5 displays the molding pressure values of the five chosen thermoplastics.

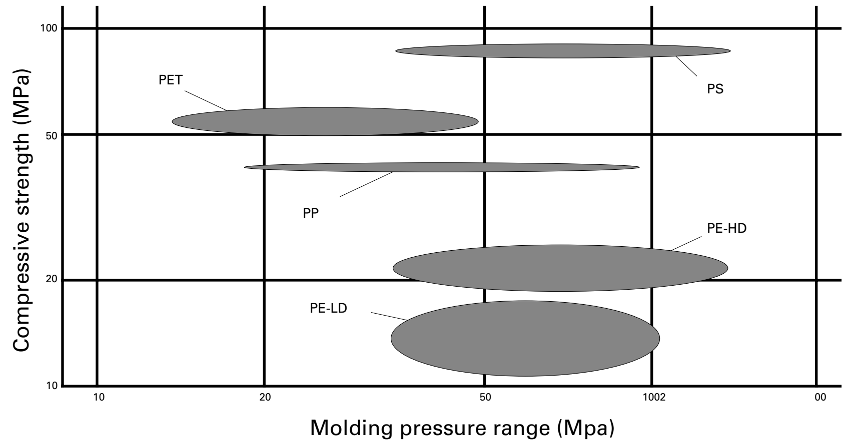


Chart 4.5 Compressive Strength vs Molding pressure comparison chart

Analyzing both comparison charts, we can foresee certain characteristics that will most likely be present during the experimentation phase.

-PET will be one of the heaviest materials to work with, while PP will be the lightest.

-PE-HD and PE-HD will not break easily.

-PS, PE-HD and PE-HD will be the hardest plastics to work with when compressed into a desired shape.

-PS may be the best material in terms of withstanding seating compressive forces contrary to PE-LD.

Since we will be working with recycled thermoplastics, all the data presented in this section may vary from the samples that are going to be tested. As mentioned in section 2.2, there are many factors that affect plastic waste, therefore, we cannot be sure about the pureness of the materials that are going to be studied.

These charts will not determine the final material for the stool's seat, this evaluation will only serve as extra information for the MDD methodology.

4.3 APPLYING MDD

4.3.1 *Steps*

This next section will focus primarily on the usage and experience of recycled thermoplastics through an MDD methodology. This technique will only target visual and tactile properties, shapes and geometries of the stool's design will not be considered since they were predefined by other factors.

Step 1: Understanding the Material: Technical & Experimental Characterization

Several actions need to be made to understand the material. A wide variety of samples and testes were applied to interact with recycled thermoplastics. The material was analyzed and experienced in several aspects, composites were made, different shapes were created, patterns and color bases were generated, and diverse finishes and manufacturing processes were implemented.

To understand the physical and mechanical properties of recycled thermoplastics through an experimentation process, a vast number of samples were made. Different shapes, processes, finishes, colors, patterns, materials, and tools, were used in this phase.

It is very important to mention that many of the samples were not created by us, many of the objects presented in this phase where made in the previous semesters with the help of several design students of the University of Porto. Although we were present during their creation, we cannot take credit for their design or outcome, permission was granted before including them in this investigation paper.

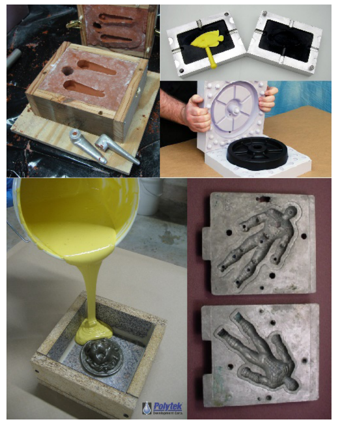


Figure 4.17 Example of diverse industrial plastic molds.

We began making samples without any type of control or pre-mediated technique, we basically started playing around with the material. The main factor that contributed in the experimentation process was the application of heat, either through a furnace, or a heat gun. Plastic needed to be heated up to re-form or modify its original shape.

We noticed that when thermoplastics are heated they can re-shaped, and when cooled down, the final desired form can be maintained. The difficult part is to keep the plastic in place throughout the cooling process, this can be made through a natural process (ambient temperature) or by adding a cooling substance to speed the process.

An easy method to retain the plastic in the desired shape is through the implementation of molds (Figure 4.17). We started using diverse metal molds (Figure 4.18), most of them are used for kitchen activities, due to their easy access.

Figure 4.18 Different metal molds used during the experimentation phase.

Shredded or granulated recycled plastic was placed inside the metal mold, and several molds were introduced in a pre-heated ceramic furnace. They were retrieved when all the plastic was in a molted or viscous state. Metal was the initial material applied in molds because it was readily found, cheap and most important, endured the furnace's temperatures.

When thermoplastics cool down, we noticed that they shrink (Figure 4.19) a small percentage of their initial form, this volume reduction varies depending on the thermoplastic being used.

All materials size change when summited to high temperatures, in the case of plastics, they tend to change in a more complex form. Their fiber-like molecular chains affect the volume as they are processed or heated (Fischer, 2012). Although the shrinkage noticed in the samples was minimum, this may have big impact when making bigger objects or when small tolerances are needed.

Figure 4.19 Plastic contraction or shrinkage after cooldown (areas marked in red).

Thanks to the shrinkage factor, the plastic could be easily removed (Figure 4.20). However, this was not the case every time (Figure 4.21), either we needed to destroy the mold while trying to recover the sample, or the material was drilled or cut. When the walls of the mold are not completely smooth, plastic can adhere in the cooling process, lubricants or industrial coatings could be applied to help with this issue. In this phase, no tests where made with lubricated molds.

Figure 4.20 Easy removal of plastic object from metal mold.

Figure 4.21 Adherence of residue or entire sample to metal mold.

Another idea we implemented to fix this mold issue was the use of parchment paper, since we were operating in normal food temperatures ranges (160-250 °C), we though this protective paper could be of help. Sadly, due to the long periods of furnace time, the parchment paper burned (Figure 4.22), staining the plastic and practically disintegrating during the heating process.

Throughout a long trial and error process, we discovered that polished stainless-steel molds were the best option to avoid the samples getting stuck.

Figure 4.22 Burnt parchment paper after being inside furnace.

Also, in some cases, water was used as a cooling agent, thus, normal metal molds could rust over time and roughen the walls, promoting the mentioned problem. Kitchen molds, were the preferred molds; however, the only big issue with stainless steel is that custom made molds could be have an elevated price.

Since plastics do not absorb water, this was the preferred substance when seeking to rapidly cool melted plastic. The big disadvantage of speeding the cooldown is the uncontrolled physical deformation (Figure 4.23).

Figure 4.23 Adding cold water to the hot plastic, made the entire object warp with no control.

As mentioned before, molten plastic suffers compaction and shrinkage throughout its cooling process, if a cool substance or surface is suddenly contacting a specific hot area, it will abruptly reduce its volume. This could be avoided by cooling down all areas of the sample at the same time, however, geometry, volume, and mass variations, make this action difficult. We noticed that even if chilled down quickly inside a full bucket of water, the inside of the object could still be in a molten form and due to the plastic's porosity, the water reached the center at different sections within different times.

Figure 4.24 Porosity present in different samples

With help of technology and advanced machinery, this water cooling technique is efficient and currently used in the polymer industry. In our case and with our limited options, this method was not effective since we had no control over the abrupt deformations caused by the quick shrinkage.

A big negative characteristic we noticed when working with thermoplastics was the appearance of porosities or bubbles on the created samples (Fig-

Figure 4.25 (top to bottom) (a)Male and female metal mold, (b) same mold geometry used for compression.

Figure 4.26 Digital kitchen scale used to control the weight of plastic.

Figure 4.27 Stirring melted plastic

ure 4.24). Our first though was that the air space in between the shredded particles was creating the porosity. Trying to fix this issue, we started compressing our samples with a mechanical carjack hoping that the air trapped inside the melted plastic would exit. To compress our material, we either used a male and female mold (Figure 4.25), or the same mold was used on the top and bottom (Figure 4.25).

We began to control and analyze our samples. We needed quantitative information to widen our knowledge on the thermoplastic's characteristics. We started using the same bowl-like molds so to notice changes in the samples, also, recycled plastic granules where weighted (Figure 4.26) before introducing them in the furnace.

By compressing the plastic inside the molds, some trapped air was released, volume was reduced (compared to the uncompressed samples), and since we used the same plastic mass, the density of our samples increased. After the first experiences, we observed that the outcomes had a more uniform surface and stronger characteristics. When increasing the density, we created heavier, stronger, and less porous products.

Even if porosity decreased after applying pressure, we still noticed some considerable number of holes in our samples. Worse still, we observed that it was not a constant factor, sometimes samples had barely no bubbles, while others were full with them. After some quick research and help from the company Extruplas, we learned that recycled thermoplastics liberate gases when heated due to many factors like: additives, coatings, composites, and chemicals, added during their manufacture. This means, that during the melting process the material itself liberated gas bubbles which sometimes got caught between layers, thus, when cooled down they appear as holes. After these learnings, we did notice some clear differences when using different thermoplastics, for example, when using PS, the porosity percentage was the found to be the lowest.

In recycled plastics have porosity issues different ways to be fixed. In the industry sector, most of the plastic they utilize is virgin and clean, therefore, the liberation of gases is basically null. There are industrial machines that remove this gasses during the melting of thermoplastics. In our case, we do not have access to those industrial machines and the use or virgin plastics conflicts with our main goal (using recycled plastic). If gas bubbles are being trapped during the melting process, we need to release as much of them as possible. We started taking out the samples half-way through their furnace phase to stir the melted plastic (Figure 4.27). Besides helping with the porosity issues, we noticed that heating times where reduced since it helped

Figure 4.28 Iron welded female mold.

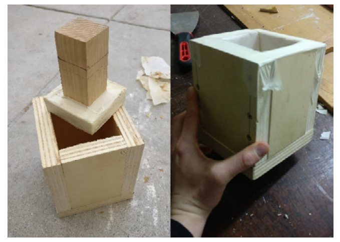


Figure 4.29 Male and female wooden molds covered with parchment paper.

Figure 4.30 Parchment paper adhere to some walls of the cube sample.

distribute temperature uniformly on all areas of the sample. Although porosity was never completely removed, this added operation helped in obtaining a better result.

As mentioned before, we were trying to control our experimentation process by creating exact shape-samples. We started out with a bowl shape but quickly discovered that the shape itself was not convenient when applying simple manufacture processes (cutting, sanding or drilling). We decided to do cube forms instead. For this, we had our own cube-shape steel mold (Figure 4.28), but after three uses, it became useless due to the lack of polished walls.

The lack of sufficient money, time or experience, made it difficult to create an efficient polished stainless-steel mold. To this, is decided to make samples using a wooden mold. The female part of the mold would be allowing the cube main shape, while the male, would only serve to compress the material, allowing alteration of the cube's height (Figure 4.29).

Wood's easiness to catch fire and its natural rough surface, made us add parchment paper to all the mold's contacting surface. Plastic needed to be melted in a metal mold and then transferred into the cube-shape wood mold. One issue of using wood molds was that the parchment paper was adhering to some areas of the sample (Figure 4.30). Thanks to the cube-shape, all sides were easily cut with a saw blade. Wooden molds have their pros and cons, until now, they have worked for the purposes needed in this experimental phase.

Presented below is the process of making a cube-shape sample:

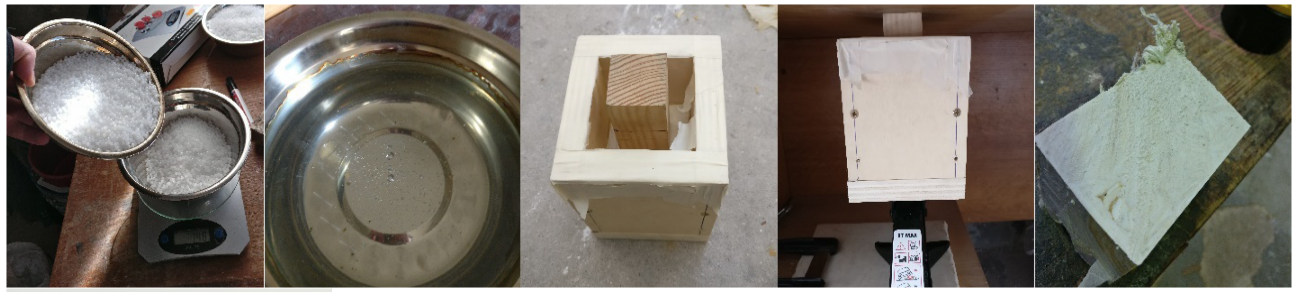


Figure 4.31 Manufacturing process of a recycled plastic cube. (from left to right) (a) Weighting correct plastic amount, (b) melted plastic inside metal mold is retrieved from furnace. (c) Placing melted plastic inside mold and applying hand pressure, (d) compressing plastic with a carjack, (e) cutting sides of cube with saw blade.

Figure 4.32 Final cube HDPE sample

Table 4.2 was made to compare the different advantages/disadvantages of utilizing metal or wood molds with recycled plastic.

Table 4.2 Comparison table between wood and metal molds.

Metal Mold		Wood Mold	
pros	cons	pros	cons
smooth and shinny finish	very expensive	cheap	unable to do final geometries
able to make final geometry	mold is hot to handle	low cooling time	plastic material waste
high durability	surface must be polished and clean	product's volume limited by mold not furnace	bad finish
easy to create high-production process	difficult to manufacture	easy to dissasemble	low compression loads
high compression loads	product's volume is limited by furnace's capability		low durability
	difficullt to dissasemble		difficult to introduce melted plastic into mold

As part of the experimentation process we decided to add some material combinations to enlarge our vision and knowledge of plastic. Even though composites or mixtures are not recommended from an eco-design's perspective, they will be created for comparison and research purposes. In attempt to re-use materials, the only elements that will be mixed with the tested thermoplastics will be wood leftovers from the testing and prototyping of the stool's legs.

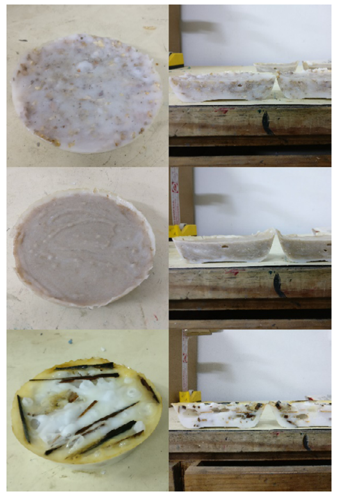


Figure 4.33 (from top to bottom) (a)HDPE and wood chips, (b) HDPE and sawdust, (c) HDPE and wood pieces.

In the first attempts, wooden pieces, chips and sawdust, were mixed together with plastic shreds inside a metal mold before entering the furnace (figure). We discovered that all the wood elements burned or either tainted the plastic, creating results that were visually pleasant.

To these errors, we decided to implement wooden molds again. We first added wooden elements inside the mold and afterwards verted molten plastic. After applying compression and allowing cooldown, the results were completely different (Figure 4.34). Given their attractive and curious aesthetics, they were added as testing samples for step three.

Figure 4.34 (from top to bottom) (a)HDPE and wood chips, (b) HDPE with wood pieces.

The big advantage of utilizing molds when manufacturing plastic pieces, is that no extra actions are needed. In other words, if designed correctly, the object will exit the mold in its final shape. Most of the plastic industries create their products through the implementation of molds, all done by automatic and expensive industrial equipment. One of the most expensive parts of mass-producing thermoplastic products is the fabrication of the metal mold. It is normally made from a solid block, containing complex patterns and shapes, all of them machined to small tolerances.

In this project, we do not have access to any of these complex machinery or tools, thus, we need to find alternative techniques that can fulfill our product's needs. We discovered that using wooden molds was the best solution to create our desired shapes, however, diverse finishing processes needed to follow. At this stage is where we started analyzing and experimenting with post-production methods.

The first and most basic post-production process we started using was a regular wood saw blade. It can be used with thermoplastics as well as with woods, this inexpensive equipment helped us rectify and create the final dimensions of our samples. Since the plastic objects were shrinking, it was easier to make bigger objects and then cut-off the leftover edges. While trimming the samples, we noticed that some plastics were melting due to friction cause by cutting (Figure 4.35). Surprisingly HDPE was the only material that supported the blade's heat. After several cutting tests we realized that melting temperatures and blade sharpness were key contributors to avoid bad edge finishes.

Figure 4.35 Melted edges of a PP samples after trimming with a wooden saw blade.

After cutting our samples some sides remained smooth while other had rough surfaces. Sanding and polishing were our best solution to this manner. Employing wood sandpapers gave a clean and smooth finish. We started with a coarse sandpaper (60 grit) and gradually incremented to a water sandpapers of 900 grit.

Sanding gave the sample a nice matte aspect and a smooth feeling, if a shiny surface was intended then we needed to polish the material. Polishing soap and toothpaste tests were compared, and the best result was provided by the using the polishing soap.

These previously mentioned methods (cutting, sanding and polishing) are considered basic activities. We needed to experiment with more complex manufacturing methods if we wanted to create better looking objects. The use of a lathe and a Computer Numerical Controlled (CNC) cutting machine were considered. Simple tests were made to see how our thermoplastic samples reacted to these manufacturing processes.

Given its easy access and with the helpful guidance of the universities' technicians, wood and metal lathe were at our disposal. A sharpened tool and high spindle speeds made the use of the lathe a great manufacturing method for recycled thermoplastic. Three different plastic (PP, PS and HDPE) pieces were made as testing samples. Some parted from a rectangle shape (wood mold) while others, from a bowl-shape (metal mold). The first piece (PP) was a sculpturing hammer, the rectangular shape was taken out of the wooden mold and sides were cut to obtain desired symmetry. A hole was made in the center and a wood cylinder was inserted, afterwards, everything was shaped in the lathe as a single piece (Figure 4.36 & Figure 4.37). The second object was made by a similar process, but using PS instead (Figure 4.38 & Figure 4.39).

Figure 4.36 (from left to right) (a) Melted plastic, (b) placing material inside mold and compressing with a carjack, (c) cutting sides with saw blade, (d) shaping and making hole in plastic piece, (e) shaping wooden handle.

Figure 4.38 (from left to right) (a) Melted plastic, (b) placing material inside mold, (c) compressing with a carjack, (d) cutting sides of cube with saw blade, (e) making shape with lathe.

Figure 4.37 Sculpting hammer made from a HDPE head and wooden handle.

Figure 4.39 Sculpting hammer made from a PS head and wooden handle.

For the third piece (HDPE), the initial form came from a bowl shape, compression was made only by hand. Afterwards, the piece was lathed to the desired shape (Figure 4.40 & Figure 4.41).

Figure 4.40 Manufacturing process of a recycled plastic bowl. (from left to right) (a)Weighting correct plastic amount, (b) melted plastic is compressed by hand by another exact mold, (c) piece is removed after cooldown, (d) sample is shaped into final design with a lathe (representation with another object).

Figure 4.41 Bowl shape object made with HDPE.

The biggest problem when using the lathe are the size restrictions. Organic shapes may be one possibility in our stool's design; therefore, we decided to analyze the recycled thermoplastic's interaction with a CNC cutting machine. Since at out university we did not have any type of CNC machine, a private company was contacted for these services. A cube shape (PS) was sent to the company along with a 3-D file of the final shape. To our surprise, the results were better than expected (Figure 4.42). Visually and dimensionally, using a CNC is so far, the best manufacturing method, however, high production times and elevated costs, are associated with this modern process.

Figure 4.42 PS sSample piece made with a CNC cutting machine.

Step 2: Creating Materials Experience Vision

Based on all the experience and knowledge obtained during step one. Now, we need to synthesize all this information to create our final product.

The first thing to do in this step is to answer some specific questions provided in Karana's article.

1. What are its unique technical/experiential qualities to be emphasized in the final application?
2. In which contexts would the material make a positive difference?
3. How would people interact with the material within a particular con-

text?

4. What would the material's unique contribution be?

5. How would it be sensed and interpreted (sensorial and interpretive levels)?

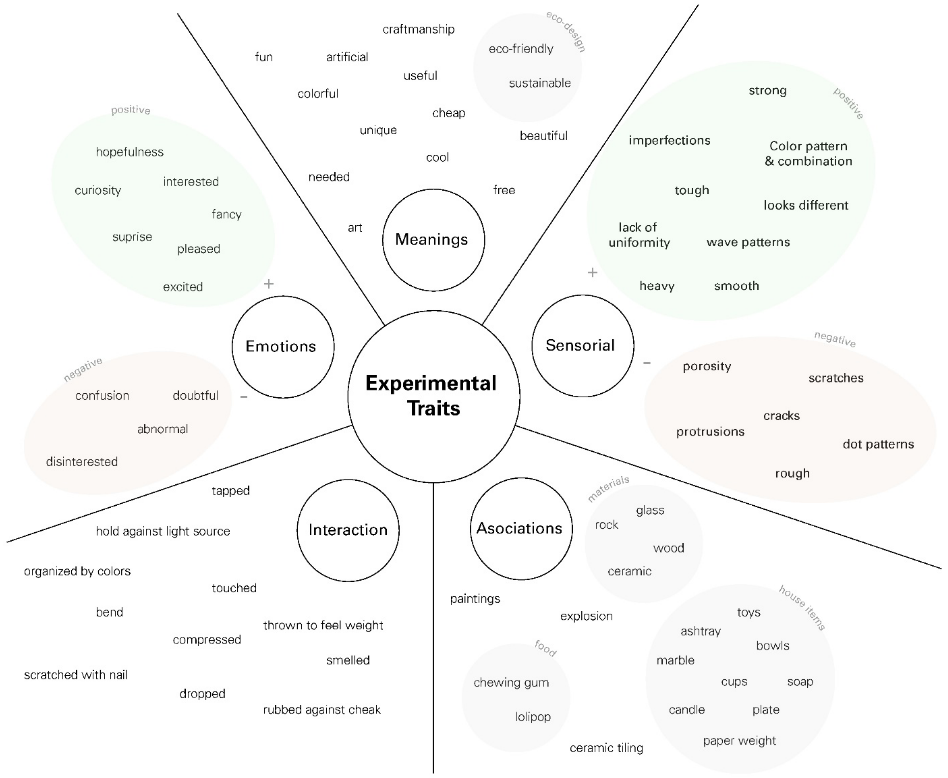
6. What would it make people do (performative level)?

7. What would be the material's role in a broader context (i.e., society, planet)?"

(Karana, Barati, Rognoli, & Zeeuw Van Der Laan, 2015)

As advised in Karana's methodology, a mind map (Figure 4.43) was created to visually represent all possible answers to these questions. This activity aided in grouping all the emotions, special characteristics, and sensorial features that were discovered during the experimental phase (step 1).

Figure 4.43 Experimental traits mind map.



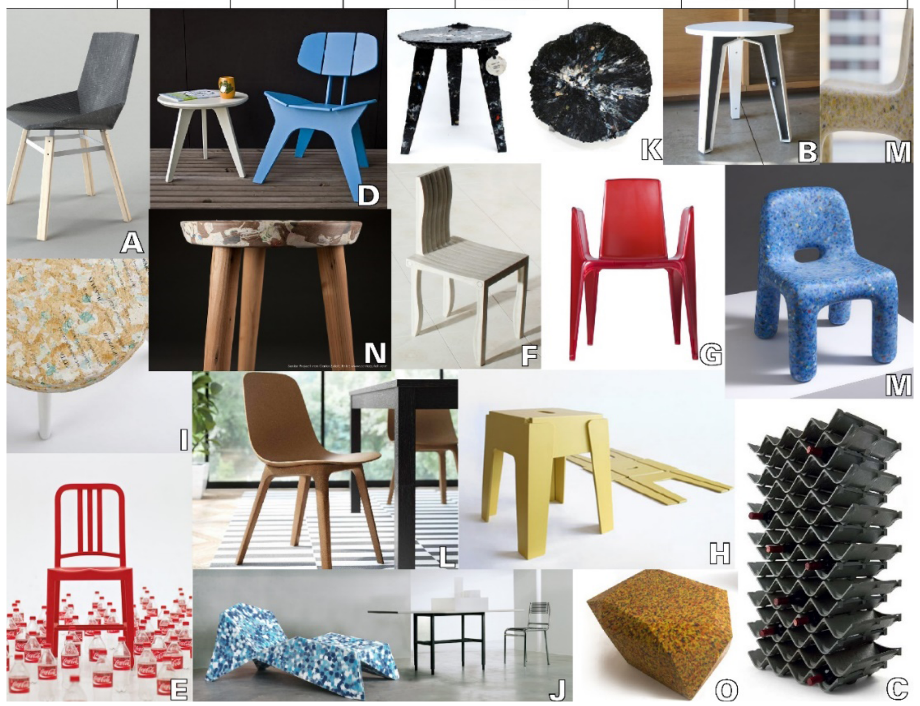
When forming this mind map, we learned that creating an opposite visual look of a common plastic is an important aspect we want to transmit in our stool's design. We tend to know what type of objects utilize plastic. Normally they use the same colors, shapes and patterns. If we go beyond the common applications and implement recycled plastic in new, different and

attractive manners, many positive feelings and experiences can be evoked. We can even change the user's pre-defined perception of a familiar material.

Karana emphasizes the importance of creating a material benchmark to see the capabilities or alternatives of products available in the market. A table (Table 4.3)was made to compare several qualities and applications between existing products that use recycled thermoplastics as their main material.

Table 4.3 Descriptive table of existing products that utilize recycled thermoplastic as their main material.

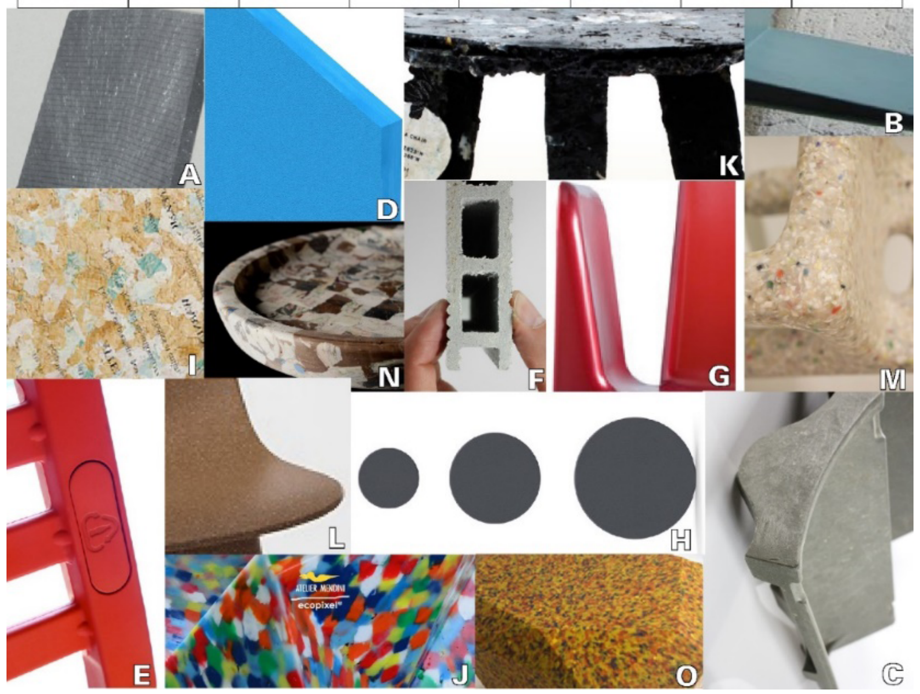
	Information	Type	Multi-Fun.	Re. Plastic	Other Mater.	Manufacture	Price
A	Green Chair	Chair	Stackable	PP with UV coat	Beechwood legs, steel frame	Injection Mold	€250
B	Possum Table	Side Table	NO	HDPE	Steel fasteners	Handmade	€170
C	ZigZag Rack	Bottle Rack	Stackable / Modular	85% Polyolefin, 15% PET, PS (Syntrewood)	NO	Mold Press	€28/unit
D	COCO	Chair	NO	HDPE with UV coat, "Metem"	S. Steel fasteners, brass inserts	Sheet extrusion, CNC cutting	€380
E	111 Navy Chair	Chair	NO	65% PET (coca-cola bottles),35% Glass Fiber	NO	Injection Mold	€390
F	10-Unit System	Modular Furniture	Modular, assemble	Recycled Plastic and Paper Composite (UPM ProFi)	Steel rods	CNC cutting	€500/10 units
G	Bella Rifatta	Chair	Stackable	77% PET, 23% Fiber Glass	NO	Injection Mold	€330
H	Butter Furniture	Stool	Stackable	80% HDPE, 20% virgin HDPE, UV coat	NO	CNC cutting	€280
I	Kulla stool	Stool	NO	50% sawdust, 50% plastic bags	Aluminum legs and inserts	Mold Press	Not for sale
J	ALEX	Chaise Lounge	NO	55% LDPE 45% virgin LDPE	NO	Pressurized, rotational	€5,700
K	Sea Chair	Stool	NO	Diverse plastics (found at beach)	NO	Mold Press	Not for sale
L	ODGER chair	Chair	NO	70% PP, 30% wood chips	NO	Injection Mold	€60
M	Chair Charlie	Chair	NO	PE (toys)	NO	Rotational-mouldered	€160
N	Müll	Stool	NO	PE (plastic bags)	Wood legs	Mold Press, Lathe	Not for sale
O	100%	Stool	NO	LDPE, coated with Zinc	Metal anchors	Rotational-mouldered	Unknown



Individually analyzing each of the product's details (Table 4.4) helped us create an expectation of what could be the final outcome with this material. Porosity, imperfections, and granulate patterns were some of the visual elements observed in most of the products analyzed. It came as a surprise that a great many of the furniture were made as composites. From an eco-design's point of view, this is not recommended, however, they were included in the experimentation phase.

Table 4.4 Descriptive table of visual details from products of Table 4.3.

	Imperfections	Pattern Ctrl.	Natural Color	Porosity Size	Finish	Craftsmanship	Shape
A	NO	N/A	RECOVERED	NONE	MATE	NO	GEOMETRIC
B	NO	N/A	NO	NONE	MATE	LOW	GEOMETRIC
C	MED	MED	RECOVERED	NONE	MATE	NO	SEMI-ORGANIC
D	NO	N/A	NO	NONE	SEMI-GLOSSY	NO	GEOMETRIC
E	NO	N/A	NO	NONE	SEMI-GLOSSY	NO	SEMI-ORGANIC
F	LOW	HIGH	RECOVERED	SMALL	MATE	NO	SEMI-ORGANIC
G	NO	N/A	NO	NONE	GLOSSY	NO	SEMI-ORGANIC
H	NO	N/A	NO	NONE	SEMI-GLOSSY	NO	GEOMETRIC
I	HIGH	LOW	REVEALED	MED	MATE	HIGH	SEMI-ORGANIC
J	LOW	MED	REVEALED	MED	MATE	NO	GEOMETRIC
K	HIGH	LOW	REVEALED	MED	MATE	HIGH	ORGANIC
L	NO	HIGH	REVEALED	NONE	SEMI-GLOSSY	NO	SEMI-ORGANIC
M	LOW	HIGH	REVEALED	SMALL	GLOSSY	NO	SEMI-ORGANIC
N	LOW	LOW	REVEALED	SMALL	MATE	HIGH	SEMI-ORGANIC
O	LOW	MED	REVEALED	NONE	SEMI-GLOSSY	LOW	GEOMETRIC



The commercial recycled products are basically divided into two branches, mass-produced and craftmanship products. Products I, J, K, N, and O are

manufactured in low quantities with no industrial process; therefore, the imperfections, porosities and protrusions are more commonly observed, adding an artistic praise. The rest of the objects are mass produced, thus, colors, shapes and details, are uniform, controlled, and constant.

Although we cannot confirm this, most of the presented furniture apply some type of coatings or additives to help preserve the physical integrity. To keep things simple, in this research paper no supplements or protective layers will be added to the plastic samples or prototypes.

Step 3: Manifesting Materials Experience Patterns

As mentioned in sub-section 3.5.2, we need to find two keywords that describe our stool's strongest qualities.

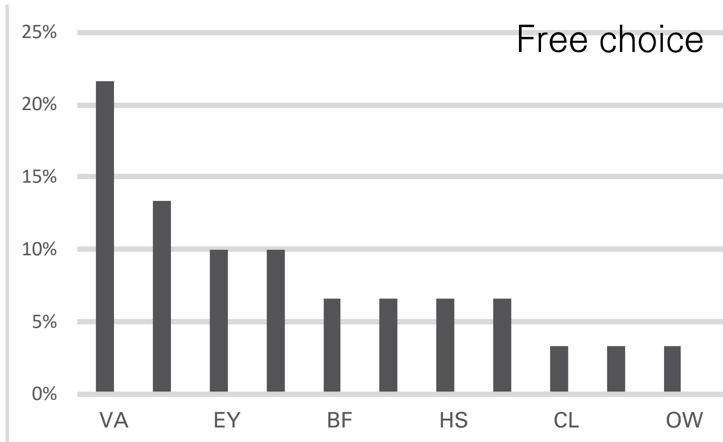
Two mood boards (Appendix 1) were used during a brainstorming session to explore and widen our project's perspective and focus. Analyzing existing products and foreseeing our future users we concluded that "elegant" and "simple" were the best choices that best represented our stool.

Tests

Not all objects created in step one were used in these evaluations. As previously mentioned, many of the used samples or objects used were made by students in previous semesters. In appendix 4, you can find the samples that were used for the tests and interviews.

The first question in test one focused in choosing a sample freely without any constrain or information. Presented below (Chart 4.6) are the results from the first stage of the MDMS test, sample "V" was the most selected with a 23%. We think that the combination of colors and the familiar shape (plate) were the reasons the participants were attracted to this peculiar object.

Chart 4.6 Test results from MDMS "free choice"



The second and most important part of the MDMS tests included the selection of a sample with a given keyword. After choosing the preferred object, the participant filled out a sensorial scale and chose an image that best represented that given keyword.

The first keyword was “elegant”, for this case, samples “A” and “B” had a 60% dominance (Chart 4.7). Our theory, is that the soft colors and the organic patterns, were the main reasons for this selection. Most participants made a comparison of these objects to marble materials.

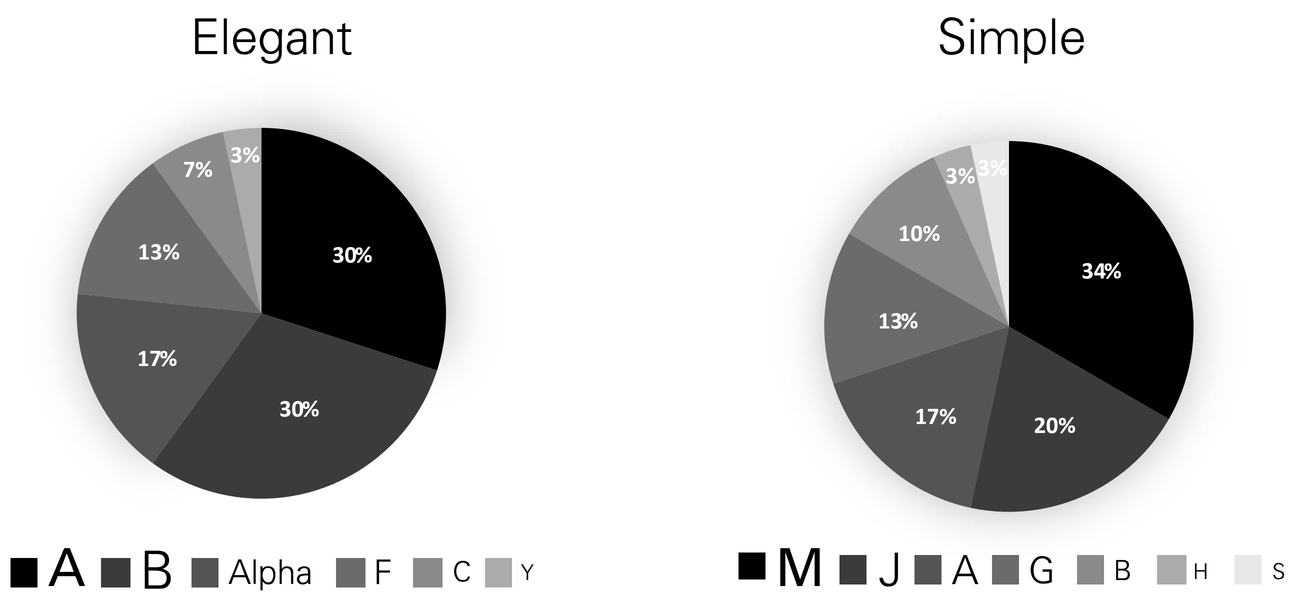


Chart 4.7 Sample choice resutls after with given keyword.

Even though we are not considering using composites or material mixtures, it was interesting to observe that sample “F” had a 13% approval. Tough its numerical values may not be considered as significant, we found it interesting that some participants considered this as an attractive sample

The second keyword provided to the participants was “simple”, as shown below (Chart 4.7), we can observe that sample “M” had a 34% preference followed by “J” with a 20%. A common characteristic from this keyword was the color white, even the third choice was predominantly white.

Gathering all the information from the MDMS tests, two mood boards (Appendix 2 & 3) were created from the images provided by the participants. In that same mood board, a chart was made to represent the results from the sensorial scales.

All the samples presented are made from the same material subcategory (recycled thermoplastics); therefore, it is expected that all the mechanical sensorial results will be similar in both the “elegant” and “simple”. The mechanical features will not be of great importance in the phase. To simplify,

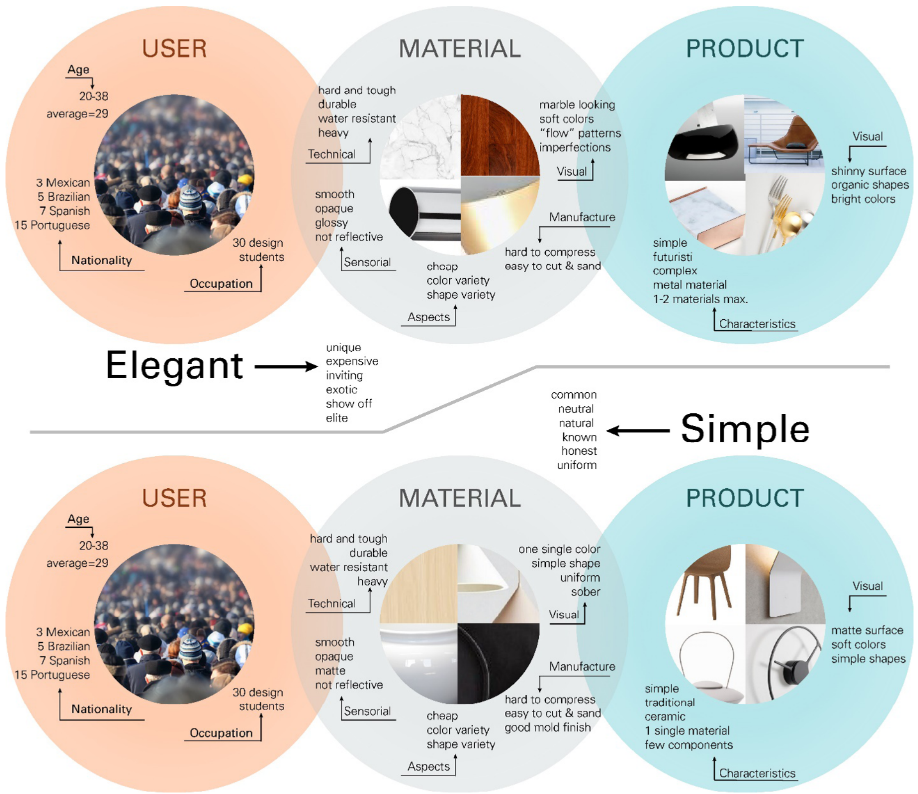
the columns highlighted in dark grey (Appendix 2 & 3) represent the visual sensorial features, these are the ones of high relevance to this project.

For the keyword “elegant” (Appendix 2), smooth, opaque, not reflective and glossy were the predominant visual features. Analyzing the mood board, we can see certain similarities or patterns. Most images shown have shinny surfaces, organic forms, combine different materials and have futuristic looks.

For the keyword “simple” (Appendix 3), smooth, opaque, not reflective, and matte are the main visual aspects. Viewing the created mood board, we see some similarities, or predominant characteristics. Most images have a matte surface, use pastel colors, apply simple geometries, and implement one uniform color.

From our point of view, the results from the MDMS tests are coherent and have an easy interpretation. As predicted, all the mechanical characteristics (not elastic, tough, hard, and strong) were the same in both keywords. This is a good indicator, since all the samples are made from the same material subcategory. Second, glossy and matte were the only opposite visual sensorial results when comparing both keywords, meaning that our future product must include all the other three features (opaque, smooth and not reflective). Following Karana’s method, a simple and colorful chart (Figure 4.44), was made to summarizes all the discussed results.

Figure 4.44 Conclusive visual representation of MDD methodology.



Two additional tests were made during this MDD phase; although they are not based on the methodology itself, they were included to expand our knowledge on the public's opinion on some specific features. The first complementary test (finish type) concentrated on knowing what type of plastic finish was preferred. In the second test (seat shape), the participant was asked to choose between two similar seat shapes only based on an aesthetic preference. The results of this last test will not be discussed in this specific section.

In the first supplementary test (finish type), the participant was handed a recycled plastic cube (sample "A") with six different sides or finishes. He/she had to choose the preferred side based on visual and physical characteristics. The results were analyzed and represented in a chart (Chart 4.8), the sanded finishing was preferred with 73% followed by polished finish with a 20%. This tendency makes sense given that most of the participants chose samples with a smooth surface during the keyword MDMS tests.

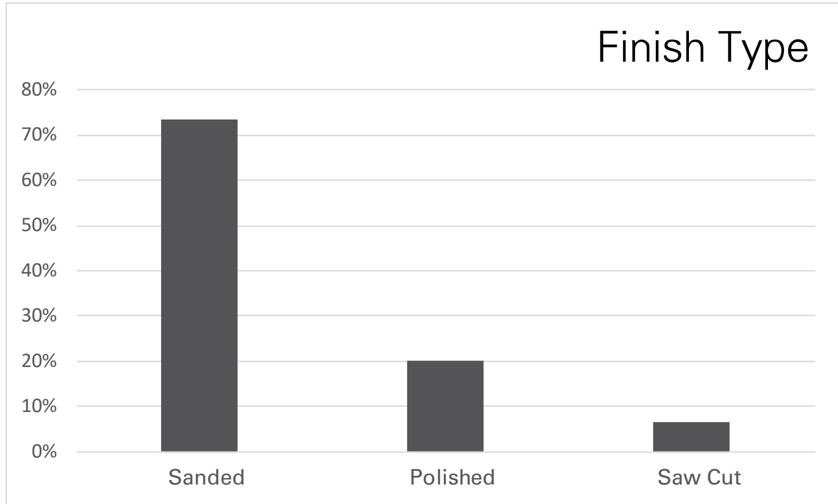


Chart 4.8 Results from the "finishing" test.

Step 4: Designing Material/Product Concept

In this project's case, step four was not applied fully since the product's geometry and layout were already defined by other contributing factors. Therefore, this specific stage was not performed fully, a similar process was made (seat shape test) during the interviews during step three.

4.3.2 MDD Conclusions

We are very pleased with the results the MDD methodology provided. It provided us a vast information on working with recycled thermoplastics. There is no better way of researching than by observing results hands on and learning from errors made.

With all the experimentation carried out in step one, we learned how this material behaves under different circumstances, and how differently it can be manufactured. We now feel capable of designing and making an aesthetic and efficient furniture made from recycled thermoplastics.

With all the experiences and learnings from step one, a comparative analysis was made between all the evaluated recycled thermoplastics. Mechanical, aesthetical and manufacturing characteristics were taken into consideration. We concluded that recycled HDPE would be the best material option for our project's design.

The MDMS tests were successful. It guided us to perceive what visual characteristics the stool's seat need to have in order to fulfill the wanted aesthetic appearance. We will create an object that has a predominant white surface, that is opaque, smooth, and not reflective. Small irregularities will be maintained creating a marble-like aspect. When seen closely, these imperfections will be noticed, and a controversy of the material's origin will arise, causing curiosity and excitement.

4.4 PROTOTYPES

All the prototypes developed will be created by the designer; in addition, help and guidance of the universities' technicians will be provided. These prototypes will be manufactured by hand or using a low-production method. Industrial processes will not be considered when elaborating the final products. This approach was chosen given the tools available, the low economic budget, and the lack of companies who wanted to sponsor this project.

When the final prototypes are done, a brief analysis will be made on how the object itself could be manufactured using a high-production method. This evaluation will only be made as a comparison on how the product can be fabricated in an industrial form. Additionally, no LCA analysis will be made.

The lack of experience and skills favored in creating all the wood prototypes in a experimental manner. Many seats and legs where made as experiments to learn how beechwood behaved and what manufacturing method best applied to our project's needs.

3-D software helped us in many ways during this project's phase. Not only did it allowed us to see a virtual image of our future design; but also, aided in the blueprints and guidelines for the manufacturing of our prototypes and experiments.

Figure 4.45 (from top to bottom) (a) Melting several layers of plastic in circular mold, (b) legs are inserted in melted plastic.

4.4.1 *First Experiences*

It was here, where the first recycled plastic and wood experiments began, an idea of creating a stool was born. In a school assignment is where we created our first stool made with a recycled plastic and wood leftovers served as the legs.

The main purpose of the school's project was to deliver a workshop that implemented recycled plastics. Our first proposition was the creation of stools that were relatively easy to make. The idea was to utilize an oven mold with the desired seat shape, melt waste plastic inside, and then simply insert the legs into the mold. Later, the legs were maintained in a fixed position and cool water was added. The quick temperature change made the plastic contract without any control, thus, the strange shape of the seat. Figure 4.45 shows a visual reference of the process.

At the end of the process, you ended up with a unique looking stool. Although the first experiment did not have any type of design or restrictions, it was enough to start an idea for a master's thesis. Our first stool was named "piñata stool" (Figure 4.46) since the seat's colors resembled a Mexican traditional festivity object.

Figure 4.46 First created stool made from recycled HDPE and wood waste.

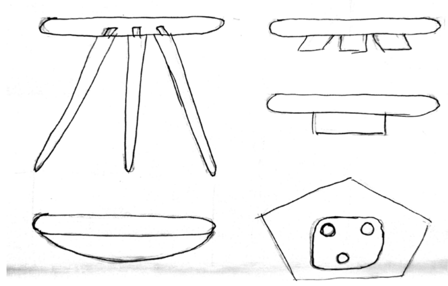
Although no advanced design was applied to the creation of the piñata stool, the first contacr emerged on how to use recycled plastic as an effective material for a stool's seating. This is considered the first unintentional prototype of this research paper.

4.4.2 *Beechwood Experiences*

Our original idea of making a modular stool/table was born from the mathematical pentagonal tiling shape (sub-section 4.1.2). Cardboard and wood prototypes (Figure 4.47) were created to observe in real scale, the shape and size of the stool's seat.

Figure 4.47 Process of wood seat prototype (from cardboard to wood)

The first ideas and sketches (Figure 4.48) tried to focus on a simple furniture. Different profiles of legs were considered (Figure 4.49). Finally, we decided to go with a tripod form using circular legs. There were several options for the shape of the legs (conic, oval or straight), these were to be analyzed further ahead.



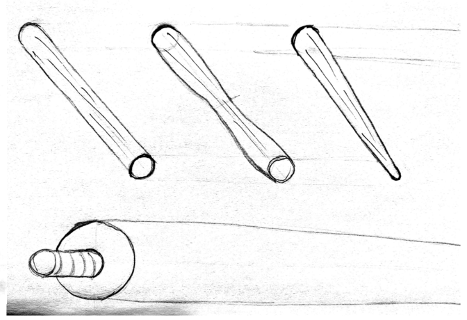


Figure 4.48 First ideas and sketches (right).

Figure 4.49 Possible leg shapes and geometries (left).

At this stage, we did not had a clear view of our final design. We wanted to keep on working with real size prototypes to analyze and make ergonomic tests and widen our knowledge of our selected wood (beechwood).

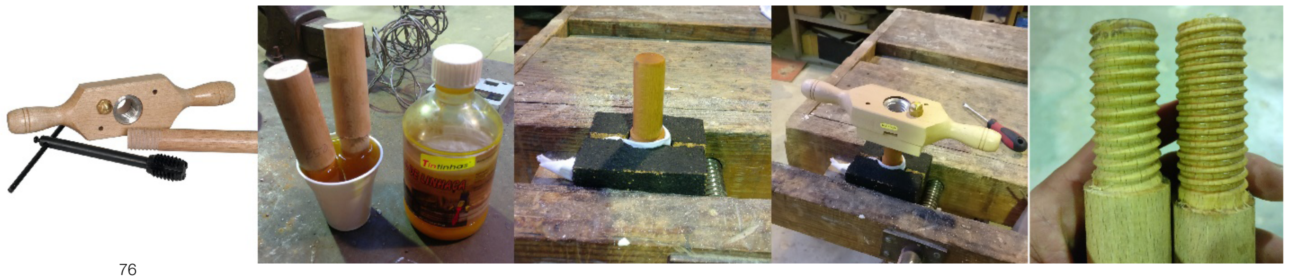
Wooden legs

The stool's legs were basically divided into three experimental phases: general shape, threading, and finishing. A conic shape was decided to be the first leg test. With help of a mechanical lathe and some pre-testing, we started making the first set of tripod legs (Figure 4.50).

Figure 4.50 Process of making beechwood conic-shape leg. (from left to right)

Figure 4.51 (from left to right) (a)Wood threading kit, (b) dipping in linseed oil, (c) piece is fixed, (d) threading machines is placed and turned clockwise, (e) final result.

The second step was threading the leg's head. For this technique, we utilize a simple yet functional threading machine. The lack of tools and experience made it hard to make the thread directly on to the lathe. Presented in Figure 4.51 is the process of making a thread on a cylindrical piece of wood.



The threading machine had a small diameter working range, we made several tests (Figure 4.52) to find out the best working size for threading. This manufacturing process made us learn a lot about the way beechwood behaves on the lathe and how can it be improved for our final design.

Figure 4.52 Threading tests on different diameters.

The third and final step was focused on the wood's finishing. There are many different types of appearances that wood can acquire. We narrowed our selection to three options: beeswax, linseed oil, and synthetic varnish (Figure 4.53). Visual, tactile, durability and sustainability analysis were made to determine the best option. Although its durability is short, we decided to go with the beeswax. This coating gave a nice and natural feel to the beechwood, without affecting its color. In addition, from an eco-design's perspective it was the best alternative.

Figure 4.53 (from left to right, this also corresponds to the order of the conic legs)(a) Varnish, (b) linseed oil, (c) natural beeswax.

4. 4. 3 *Wood Stool Prototypes*

A tripod stool prototype was made to test out the threaded legs' resistance and stability at different inclination angles (Figure 4.54). All the sides were rounded and sanded as an additional aesthetic test.

Figure 4.54 (top to bottom) (a) Tripod legs at a pronounced inclined angle, (b) legs at a closer angle.

Although the seat's material will be recycled plastic instead of beechwood, we hope that this test will help us determine the correct diameter and thread size of the wooden legs. The only real way to know if the threading system will work on a plastic seat, is to create a real size plastic seat. This will be one of the final prototypes

Visually, we preferred the wider leg inclination angle (Figure 4.55), and the conic leg-shape. When seating down, we noticed that the furniture was not stable, the stool felt weak, and the legs opened too much. Since the legs were inserted at an angle, we knew that the deeper the legs were introduced, the higher our stability would be. Due to the wood's thickness we were only able to make a threaded hole of 2.8 centimeters deep (Figure 4.56).

Figure 4.55 Type 8 first wood prototype (pronounced leg angle).

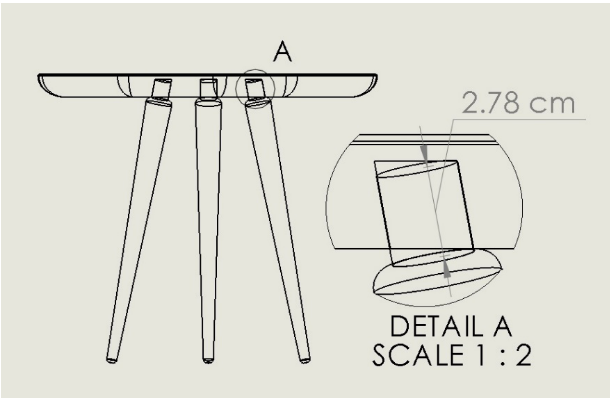


Figure 4.56 Blueprint of first prototype showing detail of thread depth.

Given the difficulty of simulating mechanical analysis on threaded wooden components, another prototype was made, just to test out different thread depths. The seat had the same type "8" shape, wooden blocks were added in the bottom of the seat so that we could make a hole of six centimeters deep (Figure 4.57). To avoid time and material waste, beechwood pre-fabricated rods where bought. Three different thread lengths were made (3.5, 4 and 4.5cm).

Figure 4.57 Type 8 second wood prototype (extended female thread).

After basic testing (seating, standing, turning while seated, moving of place and jumping on the seat) for toughness and stability, we realized that four centimeters of thread depth was more than enough for our product's needs. This meant, that we had to add wooden blocks to our type "8" shape or the whole geometry had to be extended on the bottom section. After making quick sketches (Figure 4.58), we concluded that our current seat shape had to be modified completely due to aesthetic factors.

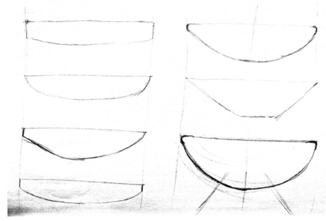


Figure 4.58 Ideas and concepts for deeper seat with a more organic and atractive shape.

Figure 4.59 (top left moving clock-wise) (a) First 3-D concept, (b) top view of stacking feature, (c) rendering of seat version with stacking units behind, (d) 3-D comparison between two different seat options.

A complete re-make of the seat's design began, all the stool's characteristics (stackable/modular, threaded holes and tripod legs) needed to be maintained. The only component we needed to change was the seat's design, it needed to withhold at least a four-centimeter depth threaded hole. After several conceptualizing sessions, we came up with a completely different design (Figure 4.59).

We were very happy with the new concept, it reflected an organic, elegant and simple aesthetic to our furniture. Also, the threaded legs were completely hidden, thus, no additional blocks or protuberance were needed. This created a smooth and single shape, the legs blended into the seat, creating a sense of permanence.

Leg protection

When using and testing our wooden prototypes, we noticed that wooden floors would easily get damaged by normal use (Figure 4.60). The small contact area, the inclination, the hardness of beechwood, and the weight of a seating user, created sufficient stress on the floor to cause damage.

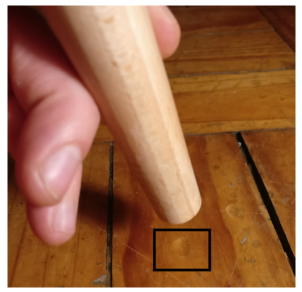


Figure 4.60 Damage (black) done to a wooden floor by normal use of the stool prototype.

We made diverse tests with different protective materials (Figure 4.61); and , either they did not work, or visually did not fit; together with our design. We even tried adding recycled plastic at the edge of the legs (Figure 4.62); however, it made no difference. After a brief investigation, we concluded that a protective piece of cork would help us solve this issue, however; due to time frames and lack of material, this experiment was not made. For the purposes of finishing this project in time, the stool's legs will remain in their natural state (no protective components will be used).

Figure 4.61 (from top to bottom) (a) Natural wood, (b) felt protective pad, (c) PP protective cap.

Figure 4.62 Leg protection made from recycled HDPE (white)

4.4.4 Foam Seat Prototypes

Our seat's shape was very similar to that of the moon, this was the main design concept to follow. Several 3-D alternatives were made (Figure 4.63) to broaden our design's possible outcomes, after a deep review, two final shape candidates were chosen (Figure 4.64).

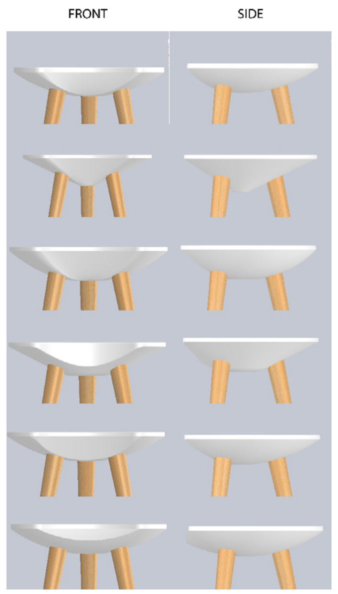


Figure 4.63 Different 3-D variations of the "moon" shape seat.

Figure 4.64 (top left moving clock-wise) (a) Aesthetic shape, (b) geometry shape, (c) comparison between both designs.

The first shape (Figure 4.65) was derived from the joinable function. The removed material was the exact geometry from the physical joining of the two seats (Figure 4.66). This design had a purpose, when placed together. The seats made a full contact between their surfaces (Figure 4.68).

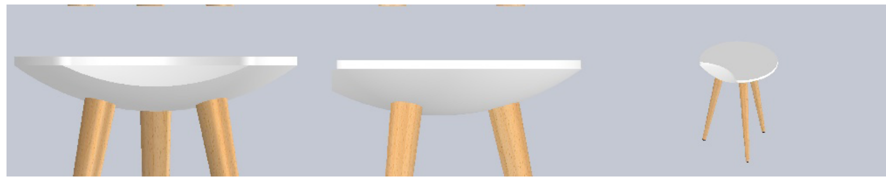


Figure 4.65 "Geometric shape", ideal connection.

The second design (Figure 4.67) was selected due to its evoking curiosity and attractive aesthetic. Although we cannot determine if something is aesthetic or not, this seat was our preferred geometry.

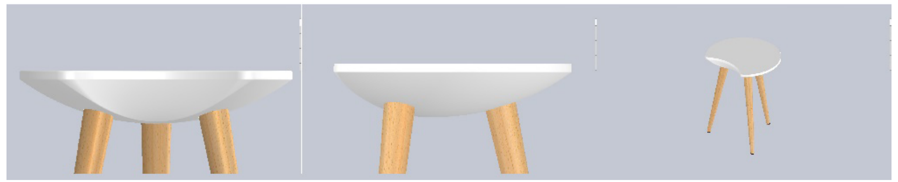


Figure 4.67 "Aesthetic shape", visualy attractive.

To help us choose between the two options, two real-size foam prototypes were made (Figure 4.69). The objects were painted and the beechwood legs were inserted to simulate their final appearance. After several meetings and discussion sessions we were not able to decide on which seat was the best option. It was then decided to make a questionnaire to observe the people's choice to these different designs. Using to our advantage, the MDD interviews, these prototypes were added to the tests, to check if there was a clear preference.

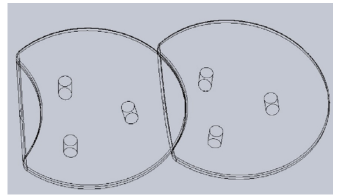


Figure 4.66 Blueprint of two geometric seats during stacking.

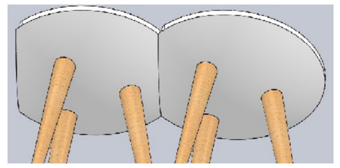


Figure 4.68 Isometric bottom view of joining two geometric shapes.

Figure 4.69 Foam seat prototypes (from left to right) (a) Material needed for the foam prototypes, (b)aesthetic shape on top of geometry shape, (c) geometric shape foam prototype with beechwood legs.

In sub-section 3.2.4 you can read the detailed steps that were taken to make this test.

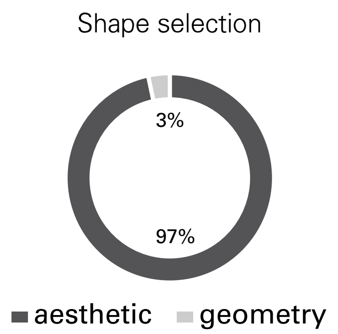


Chart 4.9 Resutls of shape test (no information given).

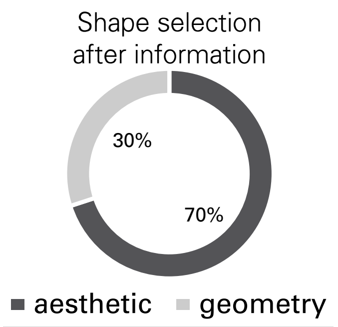


Chart 4.10 Results of shape test (design information provided).

Renders, images, 3-D models and the foam prototypes were shown to the interviewees. In the first stage, participants were asked to choose their preferred shape without giving any kind of information. They needed to select only on visual and aesthetic factors. In Chart 4.9 we can observe that the aesthetic shape (Figure 4.67) was the preferred option, by a 97%.

The next step, involved a deep explanation of how these two shapes were designed and their specific functions and differences. Afterwards, the participants were asked if they preferred the other shape or remained with the first selection. Surprisingly, some of the participants change their mind once they knew this additional information on the seat's designs (Chart 4.10).

It is important to mention that all the participants were currently studying a design degree or course. This means, that for some of the interviewees, function had a deeper meaning than aesthetic. Nevertheless, the aesthetic option won in both tests, thus; this will be the final seat's geometry.

4.4.5 *Thermoplastic Stool Prototype*

So far, we have determined the final design of our stool's legs and seat; but, still are missing to achieve a prototype that unites both components with their final materials and dimensions. Since our seat's final design has a very complex and organic shape, it cannot be manufactured with the available machines. A CNC cutting machine will be needed for this purpose, therefore; a simple shape will be made to create a functional prototype. Instead of creating a seat with a moon shape, a basic bowl-shape seat will be manufactured in the lathe. The stool's ergonomic dimensions will be maintained, so that adequate testing can be made. One of the most important aspects in this prototype, is the testing of resistance and toughness of the male-female thread joint system.

The basic bowl shape was made with a large stainless-steel kitchen mold. After compressing and allowing cooldown, the geometry was rectified and prepared for the lathe. Given the large size of the seat, we used a traditional wood lathe. In Figure 4.70 the complete manufacturing process is explained with the help of images.

We performed simple tests such as, seating, standing on top, turning while seated, moving of place, jumping, and proved that out final prototype was successful. The wooden legs were easy to attach and remove without any harm to the threads, and the plastic-wood thread connection feels stronger than the previous prototype. In conclusion, we are very satisfied with the obtained results (Figure 4.71), we have proven that this furniture type can

be made. All the acquired knowledge and experience from all the prototypes we made, will help create our final product.

Figure 4.70 Manufacturing process of HDPE round seat. (top to bottom and left to right) (a) Choosing metal mold, (b) melting of HDPE, (c) cooldown and rmeoval of piece, (d) shaping in the lathe, (e) final shape (f) female threading.

Figure 4.71 Final resutl of plastic seat prototype.

4.5 TECHNICAL SPECIFICATIONS

4.5.1 Anthropometry and Ergonomics

This furniture design is meant to work as a stool and a table. Even though it does not focus on the best physical ergonomic shape for the user, in fact, it is not designed to be seated for prolonged period of time. Still, to anthropometry standard dimensions will be applied to the product's geometry, to achieve the best possible design.

Ergonomic studies and approaches are widely used in product design, if an object is intended for human use it must have the correct mental and physical characteristics taken into consideration (Pheasant, 2014). Designing for seating requires special attention to the anthropometry dimensions of the future users, ergonomic studies and measurements can help us create a better seating device.

Since we are designing a stool, there are fewer characteristics to analyze is to those compared to a chair. Only seat height and seat depth, were the only dimensions analyzed. The user's feet should be conformably placed on the floor with a complete footrest; also, the seat must have the correct depth so that the area behind the knee is not touching the front of the seat (Openshaw & Taylor, 2007). The seat's height should vary between 14.5" (36.8 cm) and 19.5" (49.5 cm), and, its depth must not exceed 16" (40.7cm) (Tilley, 1993).

An easy way to implement and analyze ergonomic measurements, is to compare and evaluate actual products in the market. In this project, IKEA's stools and benches were used as an additional real reference for furniture ergonomic heights and sizes. This specific manufacturer was chosen due to their international reach and their free access documentation.

After reviewing literature references (Figure 4.72) and existing stool dimensions, we concluded that the height of the stool should be 18" (45.7 cm) and the seat depth will not exceed 16" (40.7 cm). Due to this product's dual functionality (stool/table) the seat's surface is completely flat and perpendicular to the floor. This may not be the optimum ergonomic solution, but, it fulfills the basic requirement to work as a viable seating and placing surface.

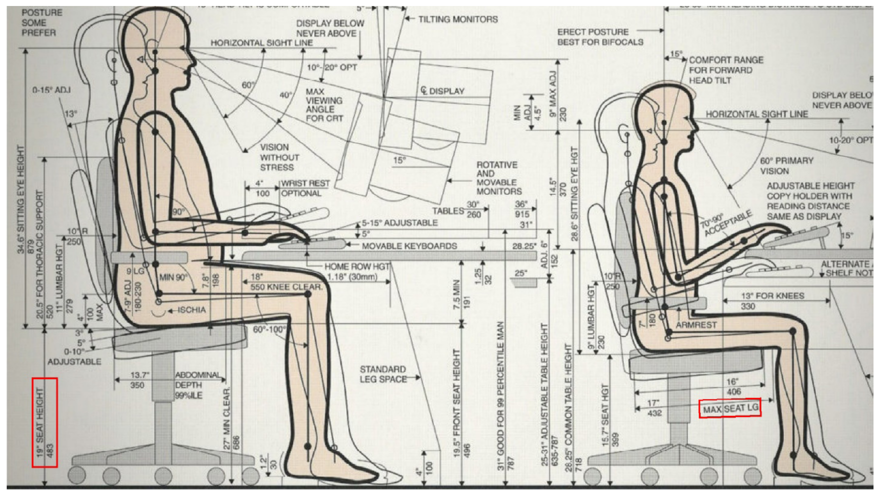


Figure 4.72 Location of seat height and depth dimensions (red box).

(Tilley, 1993)

4.5.2 Manufacturing of Recycled HDPE Seat

All the manufacturing methods in this project were implemented at an experimental level. They may be considered craftmanship actions and had no focus towards mass-production. After experiencing and testing diverse processes and techniques, we decided to combine all the acquired knowledge into a single and defined process to produce our final stool's seat.

Diverse processes and techniques were experimented and analyzed during sub-section 4.3.1, however, not all of them suited our needs. The best method that worked for us was the implementation of wooden molds with final shaping using a CNC machine.

The complete procedure divides into many actions. Instructions are presented below, and photos of this process can be seen in Figure 4.73.

1. Model your design in a 3-D software, obtain the final volume and weight of your object (applying the thermoplastic's density).

2. Convert you design into a simple and bigger geometric shape (square, rectangle or cylinder). This will be the shape of your wooden mold. Consider adding extra volume for plastic shrinkage and edge trimming.

3. Build you wooden mold in a female-male system, cover all the contact areas with parchment paper. Do not use glue in any of its components, only screws (in case the material gets stuck, the mold can easily be taken apart).

4. If utilizing HDPE, pre-heat the oven at 220 degrees Celsius. For other thermoplastics, consult the ideal melting temperatures.

5. Weigh and introduce your recycled thermoplastic pellets or shreds (the

smaller, the better) inside a inox metal container. All the component's plastic should be melted at the same time, therefore, take into consideration your furnace's dimensions.

6. Half-way through the material melting, mix all the plastic material. Afterwards, re-introduce the container into the furnace. This will help reduce air bubbles and avoid burnt spots.

7. When all the plastic is melted, transfer it to the wooden mold. Afterwards, apply compression with help of a carjack.

8. Without releasing the pressure, leave the mold for several hours to allow cooldown.

9. Remove the object from the mold and rectify all edges with a saw blade. Create a flat and uniform shape.

10. CNC cut to the desired final shape.

11. Make pre-holes at desired angles and then, use the threading machine to create the female threaded part.

12. Sand all surfaces using in every step, increased sandpaper grits.

Figure 4.73 (from top to bottom and left to right) (a) Weighing the plastic, (b) melted plastic inside metal containers, (c) wood rectangular mold to be used, (d) retrieval of piece after cooldown, (e) rectifying into uniform rectangle shape, (f) after CNC process, making pre-holes, (e) threading holes for legs.

The plastic took around four hours to completely melt, and, took eight hours to completely cool down. According to Technogial (company that provided the CNC services), the seat took almost six hours of active CNC machine time. Rectifying, trimming, sanding, and threading all together took around two hours of work.

4.5.3 *Manufacturing of Beechwood Legs*

The manufacturing of the wooden legs was not difficult in comparison to the plastic seat. When the conic shape was chosen as the final geometry, the lathe was chosen as the only viable process to produce the beechwood legs.

Since the wooden components were not the focus point of this project, no manufacturing alternatives were considered.

The steps are described below:

1. Cut square strips of solid beechwood, add extra cut-off lengths, they will serve as holding points for the lathe.

2. Shape the square strip into a uniform cylinder (the sharper the tool, the better).

3. Leave the threaded part as a uniform cylinder and carve the rest of the leg into a conic shape.

4. Use a tool to create a uniform rounded profile in the leg's end.

5. Sand using increasing sandpapers grits.

6. Add solid beeswax with help of a cloth.

7. Remove from lathe and trim excess wood.

8. Dip the future threaded tips in linseed oil for at least fifteen minutes.

9. Secure the leg (use protective wrapping material, to protect the beeswax) and use the threading kit to make the male thread.

10. Cut off the excess thread to assure equal thread dimension.

The mechanical lathe helped us create almost identical three conic-shape wooden legs. The complete process of making three conic legs took eight hours.

FINAL RESULTS

5. 1 GIBADA STOOL

The final designed product is called “Gibada”, it is spanish for gibbous. The origin for this word is due to seat’s shape that is very similar to a gibbous lunar phase.

The key aspect of this furniture is transmitting the positive outcomes of creating products that implement recycled thermoplastics in their components. The stool’s seat reveals to the user that recycled plastic can have unique and attractive forms, patterns and shapes. At first, the Gibada’s seat should give the impression of a unkown material, but once looked closer, imperfections should become obvious. Therefore, a controversy of the material’s origin will arise, causing curiosity and excitement.

The stool transmits a sense of simple elegance. The seat’s unique organic shape, should evoke interest in why that specific geometry is applied. When one stool is observed, it transmits the sense of a single and unique furniture. However, when several are seen together, it invites the user in joining them to create diverse combinations or patterns. This gives Gibada a hidden modular feature that does not appear at first sight, it arises through the need of more units, to which this multi-functional object can fulfill.

In the next pages, general and detail images of the Gibada stool are presented.

FINAL RESULTS

5.2 MATERIAL

5.2.1 *Seat*

Gibada's seat is entirely made from industrial recycled HDPE (Figure 5.1, no additives or coatings were added. After several experiments with different thermoplastics, HDPE had the best aesthetic, mechanical and manufacturing characteristics. The unique flow-like patterns and color combinations create a curious and appealing visual aspect.

Figure 5.1 Detail of recycled HDPE.

5.2.2 *Legs*

The stool's conic tripod legs are made from solid European beechwood (Figure 5.2). They have a protective layer of natural beeswax. Beechwood was chosen due to its dense and aesthetical features, the grain compaction, helped in making the leg's threaded end.

Figure 5.2 Detail of beechwood.

5.3 MANUFACTURE

The stool's seat was compressed molded into a basic geometric shape, afterwards, it was CNC cut into the final organic design. A sanding finish was given to the entire seat.

The wooden legs were shaped into a conic shape in the lathe. Both female and male threaded features were made with an artisan's threading box.

5.4 ASSEMBLY

Gibada's assembly requires no explanation at all, the threaded male and female components visually explain the method of installation. No skills or tools are needed, the flat surface at the end of the thread will inform you know how deep you should insert them.

5.5 OTHER FEATURES

5.5.1 *Modularity*

The stool's seat is designed to create a union between one or several identical stools. The legs do not go further out that the seat's geometry (Figure 5.3), thus, when joining the modular stools, the legs will not interfere. Its intuitive geometry makes it easy to make different arranging combinations or patterns, it requires no modifications, locks or adherence systems to join several stools.

Figure 5.3 3-D simulation of posible joining combinations (top view).

Figure 5.4 3-D simulation of possible joining combinations (isometric view).

When joining the stools, several combinations can be made to create different forms and uses (Figure 5.4). Examples possible additional functions include: coffee table, bench, and side table.

5.5.2 R.T.A

The threaded assembly system makes Gibada a stool easy to assemble/disassemble. This feature allows easy storage, transportation, maintenance or parts replacement.

5.5.3 Sustainability

Gibada has multiple sustainable features imbedded in the design. Below, are presented the main eco-design features.

-Solid recycled HDPE seat, with no additives, composites or coatings.

-Natural beechwood legs, with no chemical or synthetic coatings.

-The threaded joining system makes recycling, repairing and maintenance easy.

-Only composed of four parts and two different materials.

5.6 DIMENSIONS AND TECHNICAL DATA

Weight of beechwood legs= 0.8 kg

Weight of recycled HDPE seat= 3.5 kg

Total weight of stool= 4.3 kg

Basic Dimensions:

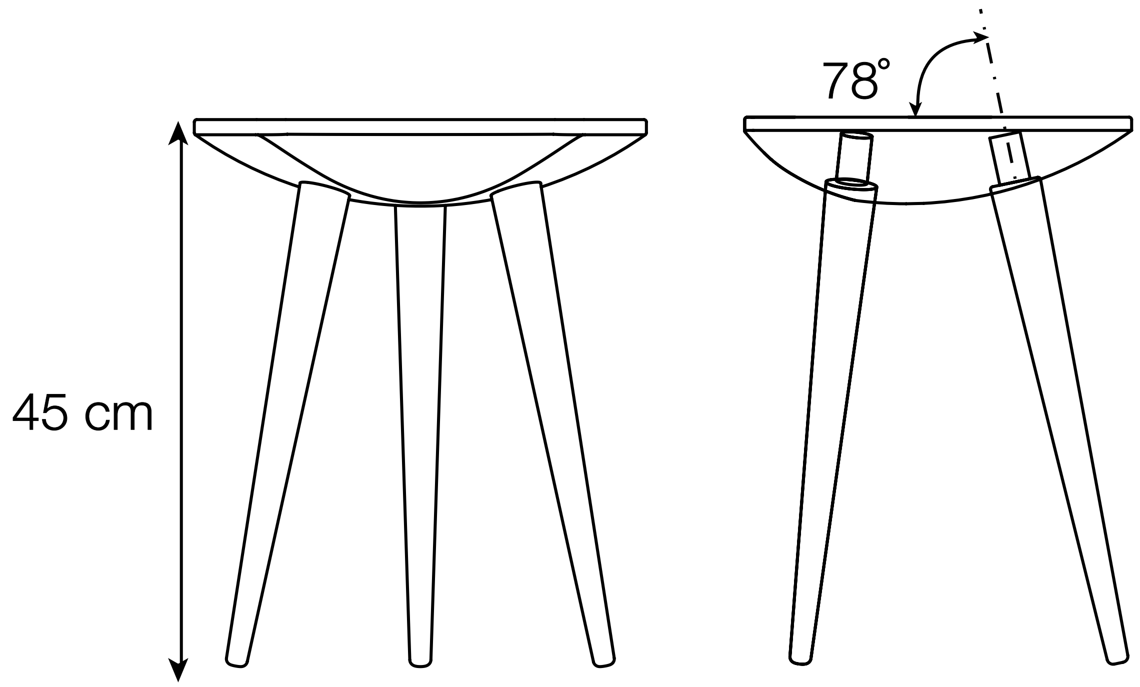


Figure 5.5 Stool's general height.

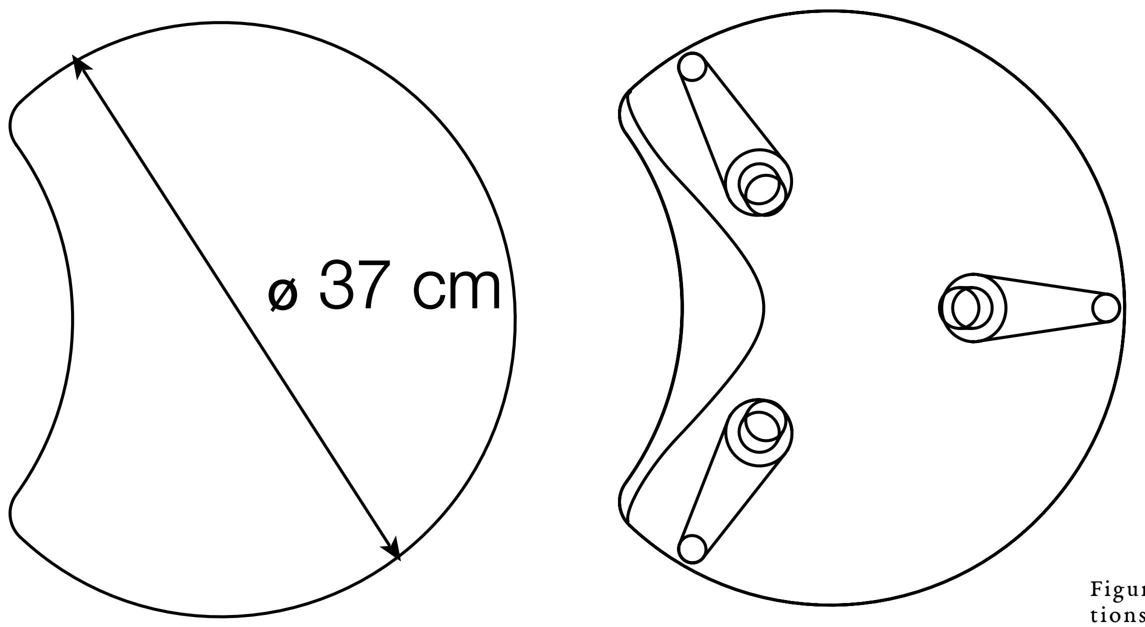


Figure 5.6 Seat Dimentions (top view).

DISCUSSION

6. 1 USING RECYCLED THERMOPLASTIC IN FURNITURE

With all the experiments and prototypes done, we feel confident enough to say, that recycled plastics can efficiently be used as main components in furniture. The results were beyond expected. Not only did we create a resistant and stable stool, we created visual patterns of the seat are completely random, yet possesses a pleasing look.

It is rewarding to know that recycled plastic can have a new and authentic purpose when applied into furniture. Not only does it offer a different look, if designed correctly, these components can offer mechanical and physical superior advantages when compared to wood, metal, or ceramics.

One big advantage of implementing plastic, are the infinite colors and patterns that can be made. One mayor advantage, is the easiness in imitating existing materials like; marble, wood, ceramic, cement, metal or even leather. The reshaping of thermoplastics offers several different outcomes in textures, colors, or finishes.

While working in the experimental phase, we utilized diverse manufacturing methods. The machines and tools we implemented were the same that are currently used in wood carpentry. We learned that plastic (in board or sheet format) can be worked almost in the same fashion as wood, it can certainly be cut, trimmed, sanded, or fixed with screws. The only disadvantage, is that plastic cannot be glued together as well as with wood, but, outside flat geometries, plastic can easily be shaped into organic forms.

After working several months with different recycled thermoplastics, we managed to acquire a considerable knowledge on diverse manufacturing methods. In the case of this project, we implemented a unique method for creating organic-shape products that utilize 100% recycled HDPE.

Although this uncommon construction technique fulfilled the purposes of this thesis, it cannot be considered a functional and viable option for an industrial production. A complete new investigation would be needed to discover the best adequate industrial manufacturing method for recycled thermoplastics. This waste matter is still considered new, we need further technological investigations to be able to explode the materials' full capacity.

In a near future, it could be interesting, if recycled plastic boards or strips could be available in any hardware store or woodshop. This way, every carpenter could easily work and implement recycled plastic in their designs or artworks.

6. 2 DESIGNING AN ECO-EFFICIENT PRODUCT

Society is more worried than ever for our ecosystem's health. Given the recent concern with plastic waste accumulation, alternatives on how to create products with recycled plastics are increasing. This ecological trend is making companies notice the new market opportunities. However, this demand on sustainable products, has no control or regulations whatsoever, thus, creating confusion and ambiguity on what can be considered sustainable.

In the case of recycled thermoplastics and furniture, this issue is no different. This ecological movement, is causing the furniture industry to implement modern and new products made from recycled goods. Many companies are changing their main materials into recycled composites, this option may be considered a viable "eco-friendly" option. However, there is no point in making a good that utilizes recycled materials and cannot be recycled again in the future.

During the elaboration of this project we had two close examples of bad recycling eco-design practices. IKEA and Extruplas, both industrial companies, manufacture furniture components made from recycled plastic composites.

Extruplas, manufactures furniture beams and strips made from a diverse combination of waste thermoplastics (PS, HDPE, ABS and others). IKEA, developed a chair called "ODGER", the furniture's seat is made from a mixture of saw dust and recycled plastic. Both products being composites, are types of mixtures that are one of the biggest enemies in recycling practices.

In addition to the mixtures of materials, they add UV protectors and diverse stabilizers to improve the product's quality. These aggregates make their products very difficult to recycle in the future. Even worse, they lack a resin coding system or label that informs on the composite's contents. We consider these practices, the biggest mistakes in the eco-friendly businesses. Even though they are utilizing recycled materials, they are making it practically impossible for future companies to re-recycle their products.

These types of actions and objects are the ones that make it difficult to recycle plastics in the first place.

The mechanical advantages and prolonged life, is what inclines the industry in preferring the usage of fillers, additives, or composites. In addition, the lack of further and deeper investigation in the efficient implementation of recycled plastics, is a contributing factor to this problem. These previously mentioned furniture examples, were one of the reasons we completely discarded the usage of composites.

When designing and manufacturing the Gibada stool, most of the pre-established eco-design guidelines were followed and applied. No LCA or detailed analysis were made to determine the real sustainable efficiency of our product. However, the main purpose was fulfilled; the main component is made from recycled plastic and the entire stool can easily be recycled again.

All the eco-design strategies applied were focused around the implementation and reutilization of recycle thermoplastics. An Eco-design mentality helped shape and create an idea into a functional and efficient product.

6. 3 MDD IN RECYCLED PLASTIC

Plastics are not a common DIY (do-it-yourself) activity. Given its complex behavior and diverse organic shapes, plastics, are regularly manufactured only in industrial facilities with advance automation and expensive machinery. These factors, make it difficult to find information on how to work with recycled plastics at a "artisan" or craftmanship level.

To this problem, MDD was our best solution. It guided us in applying the correct steps and actions to better understand more about this "new" material. Although we did not follow all the MDD steps accordingly, we feel that it was a good technique for our project's needs.

The experimentation phase really helped us understand and learn the unique characteristics of recycled thermoplastics. MDD promotes the use of prototypes, tests, and experiments. In the case of conventional materials, it gives the opportunity of discovering new applications or manufacturing methods that are yet unknown, or unused.

6.4 FUTURE WORK

This product was made and designed having in consideration several eco-design features. At the end of this project, we noticed many modifications or upgrades, that could be applied into the stool's design to facilitate its mass-production. However, most of them, collided in some manner with our pre-established eco-design guidelines.

6.4.1 Design Opportunities

Below, presented are the possible future design opportunities.

-Adding cork at the end extremity of the wooden legs as protection for both the floor and the stool

A dense cork piece would be joined together with a beechwood strip. Later, they can be shaped together in the lathe as one single piece.

-Making a hollow seat

We concluded that the weight of the plastic seat could be reduced. The only viable option would be to make it hollow. Several options could be applied, and they would all depend on the future manufacturing process.

-Using a metal mold

The lack of time and money made it difficult to create a metal mold of the stool's seat. Regardless of the manufacturing process, the metal mold would be the best solution in creating faster and identical objects.

-Protective coatings

Porosity in the plastic promotes bacteria formation, humidity accumulation, and UV sunlight degradation. In the case of wood, the beeswax tends to have a low durability and needs constant maintenance when compared to artificial coatings. Adding a water-base varnish could help us solve all the previously mentioned issues.

6.4.2 Eco-Design Opportunities

According to the eco design articles and standards (2002 International Organization of Standardization, 2002; Ljungberg, 2007; Luttropp & Lagerstedt, 2006; Rocha et al., 2011; SIEMENS, 2000; Wolfgang Wimmer & Züst, 2003) used in section 2, certain aspects were not taken into consideration and could be applied to achieve a more sustainable product.

Below, the stool's characteristics are represented that could have been improved from an eco-design perspective.

-Reduce product weight

Redesigning the seat's geometry to make it hollow, less material and energy would be needed.

-Minimize material or re-use production waste.

When manufacturing the wooden legs, wood chips and saw dust were not collected for recycling or re-use. This same happened to the plastic waste from CNC milling or rectifying.

-Employment of recycled wood in the stool's legs.

Analyzing the possibility of utilizing recycled or recovered wood instead of solid beechwood.

- Implementation of better quality materials.

The bees wax applied in the wooden legs will not provide a long protection against the environment. Although it is a natural and eco-friendly additive, it may require more maintenance in long-term uses.

-Mark or indicate the thermoplastic resin.

The stool's seat did not have any type of mark or indication of what type of thermoplastic resin was used. Following the ASTM standard, we must include the according symbols so that future users and companies are able to sort, categorize, and recycle efficiently this furniture.

6.5 INDUSTRIAL MANUFACTURING PROPOSAL

All the manufacturing methods in this project were implemented at an experimental level. They may be considered actions of craftmanship and had no focus towards mass-production. Therefore, a short analysis was made considering future manufacturing methods with an industrial focus.

6.5.1 Recycled Thermoplastic Seat

The utilized manufacturing method was the best solution for our prototype's needs, sadly, it is very complicated and expensive to repeat the entire process. It is very time consuming, has many complex and detailed steps, additionally, the CNC services normally have elevated costs. Although this process helped us create our final design, it cannot be considered a viable solution for future products.

The first change would be the amount of material being used, the seat is made from solid and compact recycled HDPE. With help of modern technology, the design could be made hollow to reduce the total weight.

Most of the plastic products are created by big and expensive industrial machinery, with help of metal complex molds, thousands of pieces can be made in a manner of minutes. Compression and injection manufacturing methods were contemplated as possible solutions.

6. 5. 2 *Wooden Legs*

The use of beechwood gives the stool an original and elegant look, this wood material can be expensive and difficult to mass-manufacture. Low-cost raw materials could be considered as alternatives, the use of recycled wood derivatives could be a viable option. The conic shape of the legs can also be modified into something simpler and more uniform. Additionally, the use the lathe can cause a lot of material waste.

6. 5. 3 *Assembly*

Threaded components integrated directly into the product's material can become a complex, time-consuming, and, expensive characteristic. In the case of the male thread, beechwood was utilized due to its dense and strong characteristics. Our current design is not meant to be assembled/disabled on a regular basis, therefore, the plastic and wood thread components would eventually degrade or break. An easy and accessible solution would be to replace the threads for metallic inserts for both male and female parts.

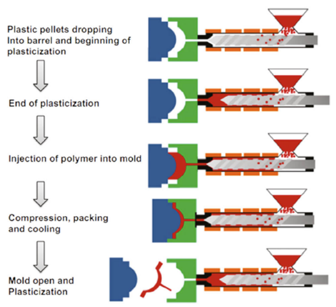


Figure 6.1 Plastic injection process diagram.

6. 5. 4 *Proposal*

Our proposal for the seat's manufacturing, would be the implementation of plastic injection (Figure 6.1) with female threads integrate in the seat's geometry . It would be composed of two sections, one would contain the female threads and the flat surface, while the second, would only serve as a covering lid (Figure 6.2).

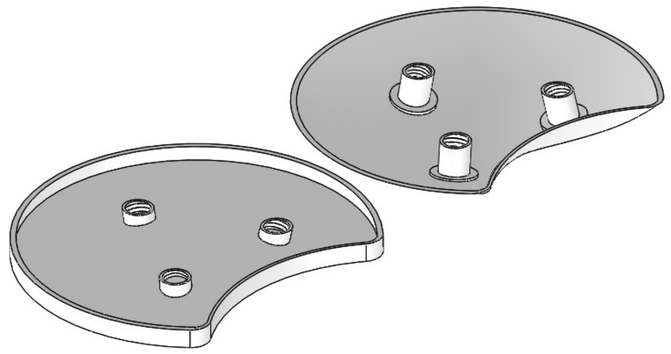


Figure 6.2 Hollow plastic seat with incorporated female threads.

The seat's two section parts could be joined with a snap-fit clamping system (Figure 6.3). No need of screws would be needed. This way, the seat can even ally be sent or shipped in a flat-pack configuration.

The stool's legs would be a changed into a simple cylindrical geomtry made from solid pinewood. The male thread would be replaced by a metallic threaded tube (Figure 6.4). This insert, would have a small tolerance to assure a good insertion, also, glue would be used to fix in place.

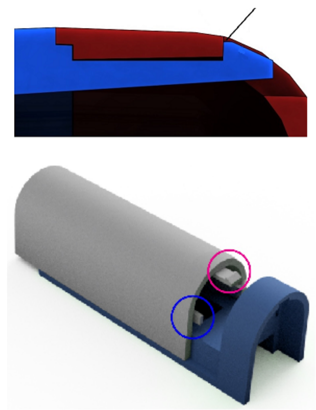


Figure 6.3 Plastic snap-fit joining system.

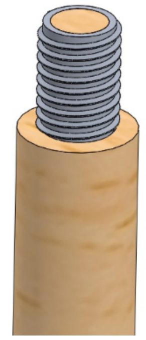


Figure 6.4 Wood Leg with male metal threaded insert.

CONCLUSION

The outcome of this project is seat stool named "Gibada". It is composed of a recycled HDPE seat and solid beechwood legs. The seat has a predominant white surface that is opaque, smooth, and not reflective, the tripod stool's legs are conic-shape and are inserted at an angle. With the creation of this product, we are proud to confirm that recycled HDPE can effectively be used as the main component in a furniture.

The central component of the stool is made from recycled plastic and the entire furniture can easily be recycled again. The stool's seat achieved an attractive and unique color pattern, the small irregularities evoke curiosity of the material's origin. Gibada, communicates the wide possibilities of products that can be done with recycled thermoplastics, thus, it promotes and raises awareness on the benefits of implementing recycled plastic in furniture design.

Even though no LCA analysis was made to the Gibada stool, we strongly believe that it can be considered an eco-efficient furniture. No harmful or toxic substances were utilized during the creation phase, and only two different materials were utilized. The threading system allows easy assemble/disassemble, making installation and recycling an easy task. No composites, additives, fillers or coats were implemented, and, most importantly, it utilizes recycled plastic.

Besides all the sustainable aspects, we also provided a furniture that is suitable for today's needs. Its ergonomic and modular design, provides other functions that may fulfill additional needs in a living space. Its assembly system allows for easy storage or transportation; this is suitable for constant reconfiguration of the available space.

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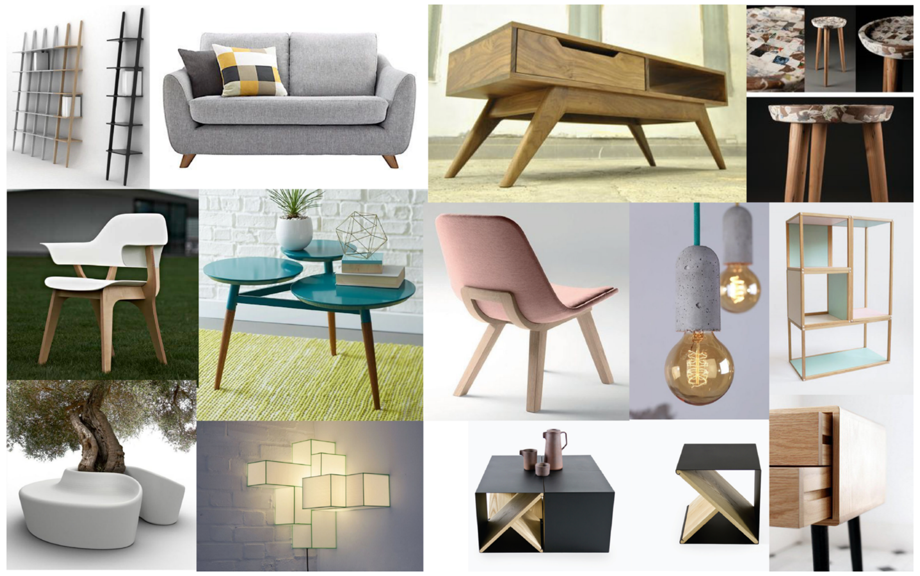
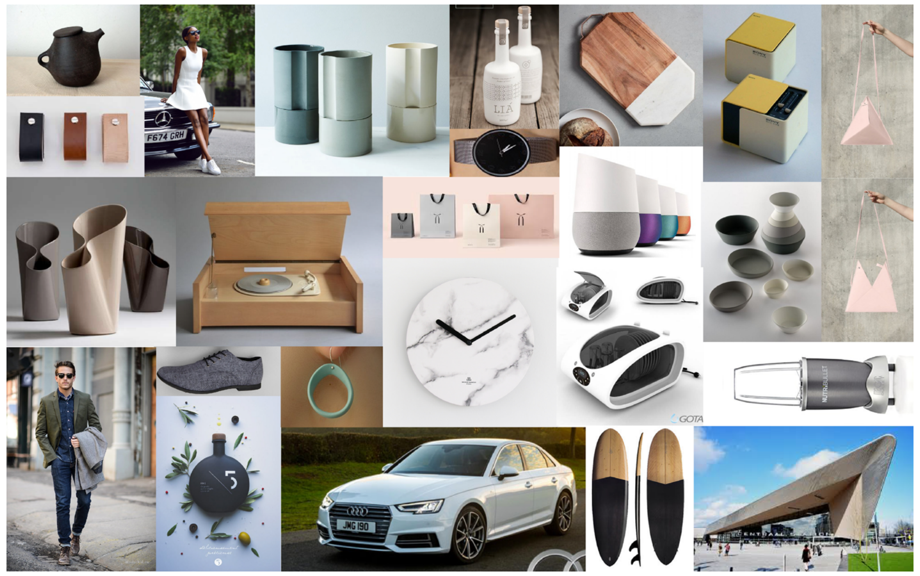
APPENDIX 1

Moodboards used for determining the stool's keywords.



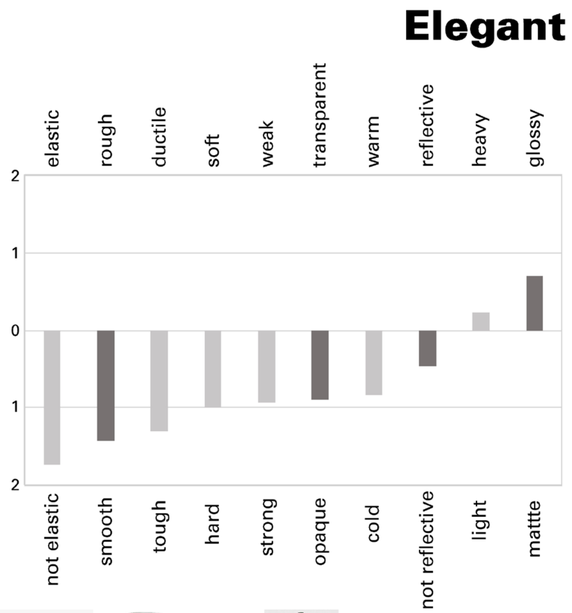


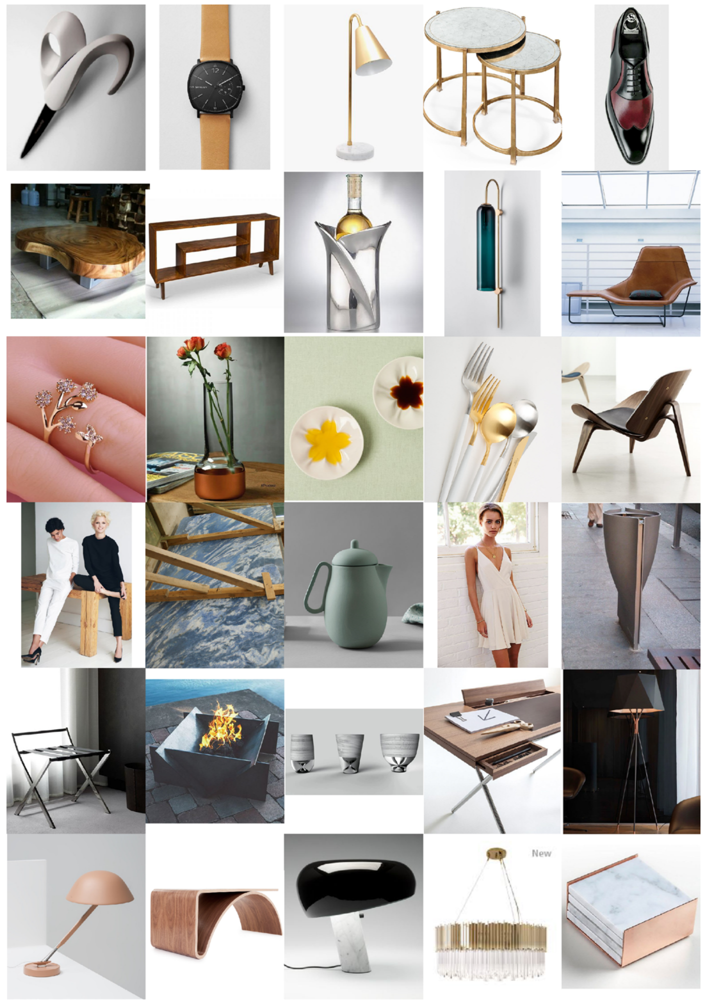
APPENDIX 2

"Elegant" moodboard

made by the participants

and sensorial scale results.

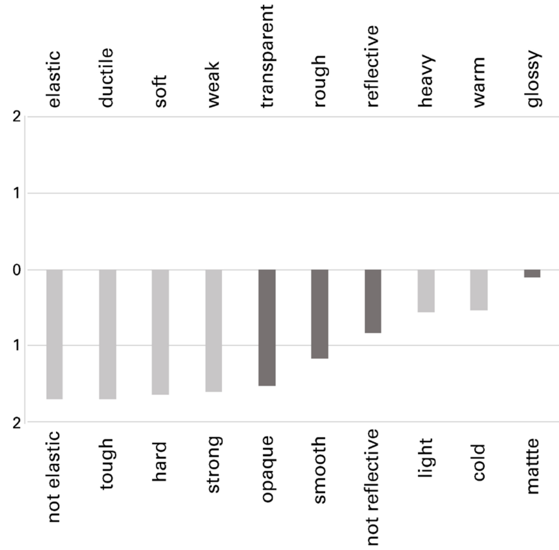


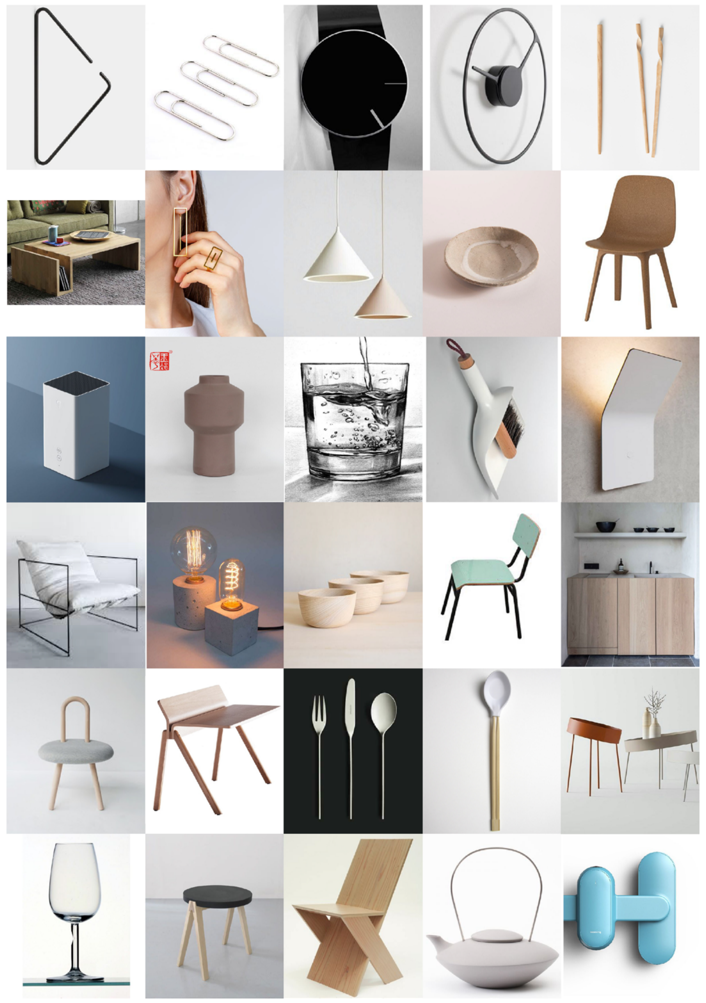


APPENDIX 3

“Simple” moodboard made by the participant and sensorial scale resul

Simple





APPENDIX 4

Recycled thermoplastics samples used in the MDD tests and interviews.

A


Plastic Type	HDPE (industry waste)
Manufacture	wood M+F compression square molding using partchment paper
Melt temp	210
Coling down	ambient temperature
Finish	saw trimmed and fine sanding

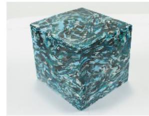
B


Plastic Type	PP (industry waste)
Manufacture	square wood M+F compression molding using partchment paper
Melt temp	180
Coling down	ambient temperature
Finish	saw trimmed and fine sanding

C


Plastic Type	HDPE (industry waste)
Manufacture	square wood M+F compression molding using partchment paper
Melt temp	210
Coling down	ambient temperature
Finish	saw trimmed and fine sanding

D




Plastic Type	HDPE (industry waste)
Manufacture	square wood M+F compression molding using partchment paper
Melt temp	210
Coling down	ambient temperature
Finish	saw trimmed and fine sanding

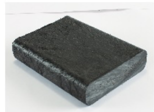
E


Plastic Type	HDPE & wood chips (industry waste)
Manufacture	square wood M+F compression molding using partchment paper
Melt temp	210
Coling down	ambient temperature
Finish	saw trimmed and fine sanding

F


Plastic Type	HDPE & wood chips (industry waste)
Manufacture	square wood M+F compression molding using partchment paper
Melt temp	180
Coling down	ambient temperature
Finish	saw trimmed and fine sanding

G




Plastic Type	HDPE, PP & others (industry waste)
Manufacture	done by “Extruplas”
Melt temp	unkown
Coling down	unkown
Finish	unkown

H


Plastic Type	HDPE, PP & others (industry waste)
Manufacture	done by "Extruplas"
Melt temp	unkown
Coling down	unkown
Finish	unkown

I


Plastic Type	HDPE, PP & others (industry waste)
Manufacture	done by “Extruplas”
Melt temp	unkown
Coling down	unkown
Finish	unkown

J

Plastic Type	HDPE (industry waste)
Manufacture	same metal mold (bowl shaped) used for both M+F compression
Melt temp	210
Coling down	ambient temperature
Finish	shinny due to metal mold

K

Plastic Type HDPE (industry waste)

Manufacture free form, placed moelted-plastic on top of a can and material fell by gravity

Melt temp 210

Coling down ambient temperature

Finish none

L

Plastic Type HDPE (industry waste)

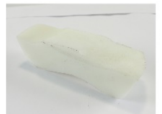
Manufacture same metal mold (bowl shaped) used for both M+F compression

Melt temp 210

Coling down ambient temperature

Finish shinny due to metal mold

M



Plastic Type HDPE, PP & others (industry waste)

Manufacture same metal mold (bowl shaped) used for both M+F compression

Melt temp 210

Coling down ambient temperature

Finish shinny due to metal mold

N

Plastic Type LDPE (grocery bags)

Manufacture food metal can used as a mold, several layers where applied, each one being compressed with hand pressure

Melt temp 110

Coling down ambient temperature

Finish texture due to metal mold

O

Plastic Type PP (kitchenware)

Manufacture food metal can used as a mold, several layers where applied, each one being compressed with hand pressure

Melt temp 180

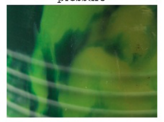
Coling down ambient temperature

Finish shinny & texture due to metal mold

P

Plastic Type PP (kitchenware)

Manufacture food metal can used as a mold, several layers where applied, each one being compressed with hand pressure



Melt temp 180

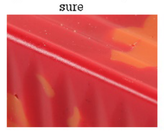
Coling down ambient temperature

Finish shinny & texture due to metal mold

Q

Plastic Type PP (kitchenware)

Manufacture food metal can used as a mold, several layers where applied, each one being compressed with hand pressure



Melt temp 180

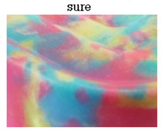
Coling down ambient temperature

Finish shinny & texture due to metal mold

R

Plastic Type PP (kitchenware)

Manufacture food metal can used as a mold, several layers where applied, each one being compressed with hand pressure



Melt temp 180

Coling down ambient temperature

Finish texture due to metal mold

S

Plastic Type HDPE (industry waste)

Manufacture same metal mold (shot shaped) used for both M+F compression

Melt temp 210

Coling down ambient temperature

T

Plastic Type PET (industry waste)

Manufacture square metal mold, no compression

Melt temp 250

Coling down cool water

U

Plastic Type HDPE, PP & others (industry waste)

Manufacture same metal mold (rectangular shaped) used for both M+F compression

Melt temp 210

Coling down ambient temperature

Finish none

V

Plastic Type HDPE (industry waste)

Manufacture same metal mold (plate shaped) used for both M+F compression

Melt temp 210

Coling down cool water

Finish shinny due to metal mold

W

Plastic Type PET (industry waste)

Manufacture square wood M+F compression molding using partchment paper

Melt temp 250

Coling down ambient temperature

Finish saw trimmed

X

Plastic Type PP (industry waste)

Manufacture square metal mold, no compression

Melt temp 180

Coling down ambient temperature

Finish none

Y

Plastic Type PET (industry waste)

Manufacture bowl metal mold, no compression

Melt temp 250

Coling down cool water

Finish none

Z

Plastic Type PP (bottle caps)

Manufacture pressed between two metal plates, then rolled into final shape

Melt temp 180

Coling down ambient temperature

Finish shinny due to metal mold

ALPHA

Plastic Type PP (bottle caps)

Manufacture pressed between two metal plates, then rolled into final shape

Melt temp 180

Coling down ambient temperature

Finish shinny due to metal mold